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# Quality Assessment and Accessibility Applications of Crowdsourced Geospatial Data

## A report on the development and extension of the George Mason University Geocrowdsourcing Testbed

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# Abstract

This report documents research efforts in quality assessment, recruitment, training, and the development of application extensions for the George Mason University (GMU) Geocrowdsourcing Testbed. The GMU Geocrowdsourcing Testbed is designed to capture, evaluate, and utilize crowdsourced geospatial data associated with transient obstacles and navigation hazards in the region surrounding the GMU campus in Fairfax, Virginia. We present our quality assessment research based on best practices, and discuss its deployment within our system. We present our training and recruitment program and discuss its future directions and future efforts to recruit and train participants. Finally, we present extensions of our geocrowdsourcing testbed in areas of accessible routing and visualization, which are ongoing focus areas for our research. The results of this research have military application for hazard identification and reporting in similarly built environments, as well as for navigation by disabled soldiers and veterans.

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# Preface

This report is a deliverable product of Department of the Army Broad Agency Announcement (BAA) #AA10-4733, Contract #W9132V-11-P-0011. The study for this report was conducted jointly by the Engineer Research and Development Center (ERDC) technical lead Douglas R. Caldwell and George Mason University faculty and research staff, in support of the ERDC. Report author Matthew T. Rice wishes to acknowledge the support of Fabiana I. Paez and Rebecca M. Rice, for their proofreading and editorial support, College of Science Dean Peggy Agouris for her support, and Department of Geography and Geoinformation Science Chair Anthony Stefanidis for his direction and support.

# Unit Conversion Factors

| Multiply | By | To Obtain |
|---|---|---|
| feet | 0.3048 | meters |
| miles (nautical) | 1,852 | meters |
| miles (U.S. statute) | 1,609.347 | meters |
| miles per hour | 0.44704 | meters per second |

# 1 Introduction and Background

In August 2005, Hurricane Katrina struck the Louisiana and Mississippi coastlines, causing an estimated 108 billion dollars in damage and more than 1,800 fatalities. It was the costliest tropical storm and one of the deadliest tropical storms to ever hit the United States.[1] FEMA, NOAA, and several other federal agencies used remote sensing, geographic information systems (GIS), and other geospatial tools to provide forecasts, predict storm surges, map inundation, and afterward, assess the massive damage caused by the storm. FEMA's inundation map of the Mississippi Gulf Coast (excerpt, Figure 1), produced with GIS using detailed elevation data, underscores the usefulness of GIS in predicting and assessing the dynamics of tropical storms. The post-Katrina reconstruction along the Gulf Coast has been guided by these FEMA "Katrina Recovery Maps," produced with the help of GIS.

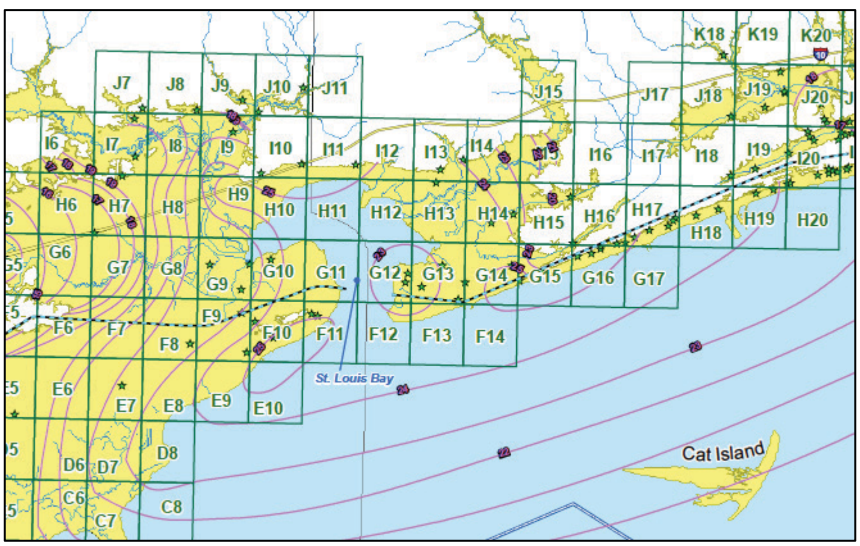


Figure 1. Excerpt, FEMA August 2005 inundation map of Mississippi coast.[2]

[1] Richard D. Knabb, Jamie R. Rhome, and Daniel P. Brown, *Tropical Cyclone Report: Hurricane Katrina, 23-30 August 2005* (National Hurricane Center, 2005).

[2] http://www.fema.gov/pdf/hazard/flood/recoverydata/ms_overview.pdf [accessed September 4, 2014]

In January 2010, another natural disaster struck when a catastrophic earthquake hit Port-au-Prince, Haiti, causing an estimated 15 billion dollars in damage and killing more than 150,000 people. Without the benefit of elaborate predictive models, high-resolution elevation data, and a significant government GIS capability, the relief efforts and prospects in Haiti looked much bleaker than those in New Orleans less than five years earlier.

The time period between the 2005 Katrina event and the 2010 Haitian Earthquake saw several significant technological changes and developments, most notably, the increase in the public's awareness and use of social media. The public engagement in the production of information and the sharing of that information on the Internet has been an important cultural development over the time period. Howe (2006, 2008) characterizes one significant form of public engagement as crowdsourcing, where "a task traditionally performed by a designated agent is outsourced by making an open call to an undefined but large group of people".[3,4,5] The permeation of Howe's crowdsourcing concept into the geospatial community between 2006 and 2010 resulted in a very fortunate confluence of people, technology, and social movements, described best by Zook et al. (2010), where crowdsourcing, GIS, citizen-led open source mapping, non-profit organizations, and government agencies collaborated in a large volunteered mapping and data generation effort to assist disaster relief efforts in Haiti immediately following the earthquake. Zook et al. describe this effort as "a remarkable example of the power of crowdsourced online mapping and the potential for new avenues of interaction between physically distant places".[6] The geocrowdsourcing efforts described by Zook et al. may turn out to be historical hallmark events in the evolution of GIS toward an end-user-centered, open system.

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[3] Jeff Howe, "The Rise of Crowdsourcing," *Wired Magazine* 14, no. 6 (2006): 1–4.

[4] Jeff Howe, *Crowdsourcing : Why the Power of the Crowd Is Driving the Future of Business* (New York: Crown Business, 2008).

[5] http://www.bizbriefings.com/Samples/IntInst%20---%20Crowdsourcing.PDF [accessed Sep. 4, 2014]

[6] Matthew Zook et al., "Volunteered Geographic Information and Crowdsourcing Disaster Relief: A Case Study of the Haitian Earthquake," *World Medical & Health Policy* 2, no. 2 (July 21, 2010): 6–32, doi:10.2202/1948-4682.1069. p.7.

## Crowdsourced Geospatial Data

One of the most important and strategic contemporary trends in the geospatial sciences, underscored by the Haitian earthquake response, is the use of map-based crowdsourcing for collecting, confirming, editing, and displaying geospatial data. Goodchild (2007, 2009) and many other recent authors cite several significant benefits associated with this general approach; namely, the local geographic expertise of the contributors, who are more familiar with the local features being mapped; the speed with which information can be collected and mapped; and finally, the greatly reduced costs associated with what is typically a very expensive activity.[7,8]

In the military and intelligence communities, the field-based collection of time-relevant geographic information is a critical aspect for supporting operations, particularly in urban environments, where people, places, activities, events, and other items of interest change very quickly. There is often no practical way to capture data about the location and nature of these rapidly unfolding geographic events using traditional geospatial data collection methods. In many settings and circumstances, traditional data collection methods work well, but under other circumstances, geo-crowdsourcing may offer a distinct advantage.

In their 2012 technical report, Rice et al. provide a comprehensive overview of the emerging phenomena of crowdsourced geospatial data and the advantages associated with this data production paradigm. They compare and contrast geocrowdsourcing techniques with traditional geospatial data production activities, discuss quality assessment methods, and review several emerging geocrowdsourcing applications.[9] As concluded in the final chapter of their report, crowdsourced geospatial data presents many strategic advantages and significant challenges, and can be characterized as an important additional tool within the complete toolkit available to the geospatial community. The methods used and benefits obtained by prominent geocrowdsourcing practitioners in other domains (emergency manage-

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[7] Michael F. Goodchild, "Citizens as Sensors: The World of Volunteered Geography," *GeoJournal* 69, no. 4 (December 2007): 211–21.

[8] Michael F. Goodchild, "NeoGeography and the Nature of Geographic Expertise," *Journal of Location Based Services* 3, no. 2 (June 2009): 82–96, doi:10.1080/17489720902950374.

[9] Matthew T. Rice et al., *Crowdsourced Geospatial Data: A Report on the Emerging Phenomena of Crowdsourced and User-Generated Geospatial Data*, Annual (Fairfax, VA: George Mason University, November 29, 2012), http://www.dtic.mil/dtic/tr/fulltext/u2/a576607.pdf.

ment, humanitarian response, natural resource protection, transportation, and accessibility) can offer insight to practitioners in the military or intelligence domains, where geocrowdsourcing techniques can offer benefits, but should be considered carefully. Many of these compelling application domains and resulting lessons learned have been characterized and discussed by Rice et al. (2011, 2012a, 2012b, 2013)[10,11,12,13], Zook et al. (2010)[14], Sui et al. (2013)[15], and Liu et al. (2010)[16]. Where relevant and useful, conclusions and insights from these works will be presented in this report.

## Crowdsourcing Transient Navigation Obstacles

To extend previous research work (Rice et al. 2005, Golledge et al. 2005, Golledge et al. 2006),[17,18,19] and to provide a useful application of geocrowdsourcing, Rice et al. (2013) presented the conceptual design of a system for collecting transient obstacle information to assist blind, visually-impaired, and mobility-impaired individuals navigate through unfamiliar environments.

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[10]Rice et al., "Integrating User-Contributed Geospatial Data with Assistive Geotechnology Using a Localized Gazetteer," in *Advances in Cartography and GIScience. Volume 1*, ed. Anne Ruas, Lecture Notes in Geoinformation and Cartography (Springer Berlin Heidelberg, 2011), 279–91, http://dx.doi.org/10.1007/978-3-642-19143-5_16.

[11] Rice et al., *Crowdsourced Geospatial Data: A Report on the Emerging Phenomena of Crowdsourced and User-Generated Geospatial Data*.

[12] Matthew T. Rice et al., "Supporting Accessibility for Blind and Vision-Impaired People With a Localized Gazetteer and Open Source Geotechnology," *Transactions in GIS* 16, no. 2 (April 2012): 177–90, doi:10.1111/j.1467-9671.2012.01318.x.

[13] Matthew T. Rice et al., *Crowdsourcing to Support Navigation for the Disabled: A Report on the Motivations, Design, Creation and Assessment of a Testbed Environment for Accessibility*, US Army Corps of Engineers, Engineer Research and Development Center, US Army Topographic Engineering Center Technical Report, Data Level Enterprise Tools Workgroup (Fairfax, VA: George Mason University, September 2013), http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA588474.

[14] Zook et al., "Volunteered Geographic Information and Crowdsourcing Disaster Relief."

[15] Daniel Sui, Sarah Elwood, and Michael F. Goodchild, eds., *Crowdsourcing Geographic Knowledge Volunteered Geographic Information (VGI) in Theory and Practice.* (New York, NY: Springer, 2013).

[16] S. B Liu and L. Palen, "The New Cartographers: Crisis Map Mashups and the Emergence of Neogeographic Practice," *Cartography and Geographic Information Science* 37, no. 1 (2010): 69–90.

[17] Matt Rice et al., "Design Considerations for Haptic and Auditory Map Interfaces," *Cartography and Geographic Information Science* 32, no. 4 (2005): 381–91.

[18] Reginald G. Golledge, Matthew Rice, and Daniel Jacobson, "A Commentary on the Use of Touch for Accessing On-Screen Spatial Representations: The Process of Experiencing Haptic Maps and Graphics," *The Professional Geographer* 57, no. 3 (August 2005): 339–49, doi:10.1111/j.0033-0124.2005.00482.x.

[19] Reginald G. Golledge, Matthew T. Rice, and R. Daniel Jacobson, "Multimodal Interfaces for Representing and Accessing Geospatial Information," in *Frontiers of Geographic Information Technology* (Springer, 2006), 181–208.

Transient obstacles (Figure 2) are a difficult navigation challenge because they are usually unplanned, unmapped, unpredictable, and temporary. Navigation systems and geoassistive technology, such as the UCSB personal guidance system (Loomis et al. 2005, Figure 3)[20], offer support to the blind, visually-impaired, and mobility-impaired community, but lack the ability to incorporate real-time event and obstacle information. Several authors, notably Nuernberger (2008), Barbeau et al. (2010), Harrington et al. (2013), and Matuška (2014) have used communication devices and modeling techniques to increase the amount of information about surroundings and unplanned, transient events for blind, visually-impaired, and mobility-impaired travelers.[21,22,23,24]


Figure 2. Transient Navigation Obstacle

[20] Jack M. Loomis et al., "Personal Guidance System for People with Visual Impairment: A Comparison of Spatial Displays for Route Guidance," *Journal of Visual Impairment & Blindness* 99, no. 4 (2005): 219.

[21] Andrea Nuernberger, "Presenting Accessibility to Mobility-Impaired Travelers" (UCTC Dissertation, University of California Transportation Center, 2008).

[22] Sean J. Barbeau et al., "Travel Assistance Device: Utilising Global Positioning System-Enabled Mobile Phones to Aid Transit Riders with Special Needs," *Intelligent Transport Systems, IET* 4, no. 1 (2010): 12–23.

[23] Naomi Harrington et al., "Beyond User Interfaces in Mobile Accessibility: Not Just Skin Deep," in *Communications, Computers and Signal Processing (PACRIM), 2013 IEEE Pacific Rim Conference on* (IEEE, 2013), 322–29.

[24] Jaroslav Matuška, "Railway System Accessibility Evaluation for Wheelchair Users: Case Study in the Czech Republic," *Transport*, no. ahead-of-print (2014): 1–12.

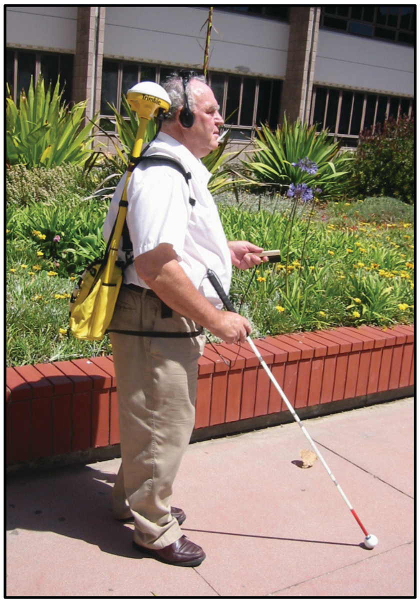

Figure 3. UCSB Personal Guidance System, circa 2003

## Crowdsourced Geospatial Data and Accessibility

Previous technical reports prepared for the U.S. Army Corps of Engineers, Engineer Research and Development Center, available from the Defense Technical Information Center, addressed underlying fundamental issues. The first report (Rice et al. 2012a) [25] addressed the emerging trend of crowdsourced geospatial data, with a comprehensive discussion of changing geospatial production paradigms, a review of geocrowdsourcing applications, a discussion of quality assessment methods adapted from traditional approaches, a review of evaluation methods and considerations for crowdsourced geospatial data, and a synopsis of significant trends and lessons learned. The second report (Rice et al. 2013) [26] reviewed the domain of geocrowdsourcing for accessibility and introduced the GMU Geocrowdsourcing Testbed prototype, developed to crowdsource and display transient obstacles and navigation hazards. The report also updated the summary of emerging trends in geocrowdsourcing.

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[25] Rice et al., *Crowdsourced Geospatial Data: A Report on the Emerging Phenomena of Crowdsourced and User-Generated Geospatial Data*.

[26] Rice et al., *Crowdsourcing to Support Navigation for the Disabled: A Report on the Motivations, Design, Creation and Assessment of a Testbed Environment for Accessibility*.

This report builds on both previous reports, and presents a body of research work associated with training and recruitment in geocrowdsourcing, quality assessment of geocrowdsourced data, and the experimental use of the GMU Geocrowdsourcing Testbed environment for accessible routing and data visualization. The second chapter of this report discusses the development of quality assessment protocols and functional quality assessment moderation within our geocrowdsourcing testbed. The third chapter addresses training activities, recruitment activities, findings, and conclusions. The fourth chapter of this report addresses experimental efforts to create accessible routing through our testbed environment, along with preliminary results and conclusions. The fifth chapter of this report revisits quality assessment and our efforts to create effective visualization techniques to assess the dynamics and data quality within our system. Finally, this report ends with a summary of activity and future plans for our work.

# 2 Quality Assessment and Moderation in the GMU Geocrowdsourcing Testbed

Quality assessment is crucial for crowdsourced geographic data (CGD), as it provides a way of measuring, understanding, and communicating critical aspects of quality, and therefore provides information to decision makers and end-users. A determination of the value and quality of information is critical to understanding whether it can be used appropriately for a given purpose.

Although the meanings of the terms "value" and "quality" are often subjective and based on circumstance and context, generally accepted notions of quality in the geospatial domain include determinations about the positional, temporal, and attribute accuracy of the information, the completeness and coverage of the data, and its sufficiency for any particular application. Guptill and Morrison (1995),[27] Veregin (1999),[28] and others have refined what we now consider to be the most important elements of spatial data quality: positional accuracy, attribute accuracy, completeness, logical consistency, semantic accuracy, temporal accuracy, and lineage. These quality assessment items and others relevant to crowdsourced geospatial data are reviewed by Rice et al. 2012a,[29] Rice et al. 2013,[30] and are articulated by Girres and Touya (2010).[31] These items will not be addressed individually in exhaustive form, having been covered in earlier reports, but will be discussed in this chapter as they pertain to the quality assessment work in the GMU Geocrowdsourcing Testbed environment, introduced in Rice et al. 2013,[32] and extended during this recent research phase.

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[27] Stephen C. Guptill, Joel L. Morrison, and International Cartographic Association, *Elements of Spatial Data Quality*, vol. 202 (Elsevier Science Oxford, 1995).

[28] Howard Veregin, "Data Quality Parameters," *Geographical Information Systems* 1 (1999): 177–89.

[29] Rice et al., *Crowdsourced Geospatial Data: A Report on the Emerging Phenomena of Crowdsourced and User-Generated Geospatial Data*.

[30] Rice et al., *Crowdsourcing to Support Navigation for the Disabled: A Report on the Motivations, Design, Creation and Assessment of a Testbed Environment for Accessibility*.

[31] Jean-François Girres and Guillaume Touya, "Quality Assessment of the French OpenStreetMap Dataset," *Transactions in GIS* 14, no. 4 (August 2010): 435–59, doi:10.1111/j.1467-9671.2010.01203.x. P. 439-440

[32] Rice et al., *Crowdsourcing to Support Navigation for the Disabled: A Report on the Motivations, Design, Creation and Assessment of a Testbed Environment for Accessibility*.

## The Nature of Error in Geospatial Data

Hunter et al. (1992) addresses quality in geospatial data by articulating the relationship between sources of error, forms of error, and resulting errors that exist in geospatial data (Figure 4). Hunter and Beard provide a useful perspective on quality, noting that error may be inherent in the information acquired for a project or it may be separately introduced by the actions of the user in processing, managing, or analyzing the data in a geographic information system (GIS) (1992, 108).[33]

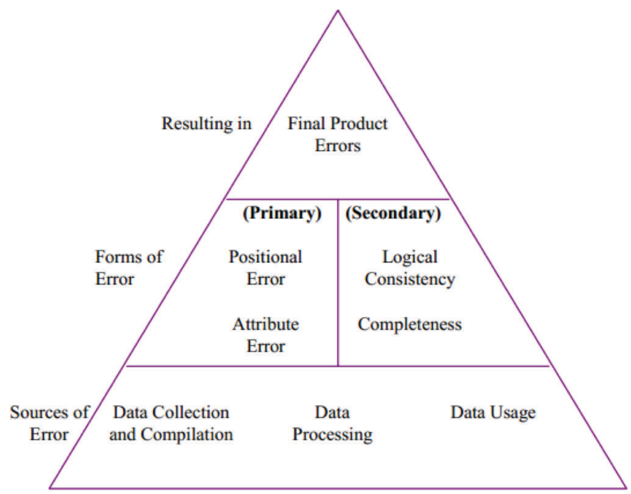


Figure 4. Hunter et al. 1992, Classification of Error in GIS, from "Understanding Error in Spatial Databases"

Based on a concept pioneered by landscape architect Ian McHarg and articulated in *Design with Nature* (1969),[34] GIS uses a map overlay technique where several thematic layers are combined to create a composite layer that contains elements of all the inputs. The map overlay is then used to address geographic problems. Figure 5, from Hill (2006)[35] shows a typical combination of thematic layers, each of which has its own unique characteristics.

[33] Gary J. Hunter and Kate Beard, "Understanding Error in Spatial Databases," *Australian Surveyor* 37, no. 2 (1992): 108–19.

[34] Ian L. McHarg and Lewis Mumford, *Design with Nature* (American Museum of Natural History New York, 1969).

[35] Linda L. Hill, *Georeferencing: The Geographic Associations of Information*, Digital Libraries and Electronic Publishing (Cambridge, Mass: MIT Press, 2006).

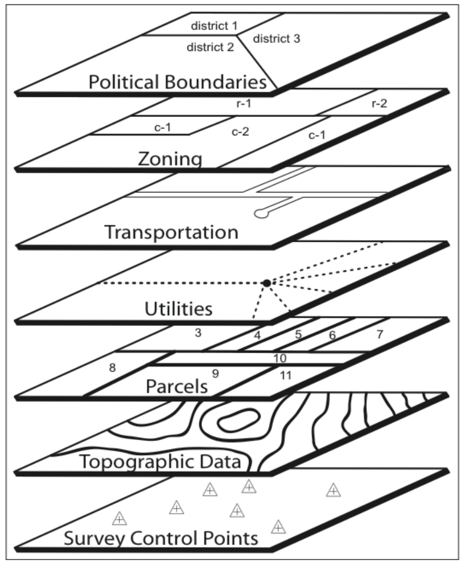


Figure 5. Thematic Layers in a GIS used for Map Overlay, from Hill (2006). Used with permission (Cartomedia.com).

Goodchild and Gopal (1989)[36] suggest that the cumulative effect of positional errors in various thematic layers during a GIS overlay (Figure 5) is difficult to ascertain and may require multiple models for error. Assessing quality in geospatial data can be complex and difficult. A comprehensive review of quality assessment concepts for crowdsourced geospatial data is contained in Chapter 4 of Rice et al. (2012a)[37] and Chapter 3 of Rice et al. (2013),[38] and practical approaches relevant to CGD are addressed in the same works.

The following sections of this chapter will discuss general quality assessment research and accepted practices, including references from key publications. Following this discussion, there will be an explanation of how these quality assessment concepts are implemented and measured in our system.

## Quality Assessment: Positional Accuracy

For geospatial data produced by U.S. Federal agencies, standards for quality assessment have been developed and are widely used. Similar stand-

[36] Michael F. Goodchild and Sucharita Gopal, *The Accuracy of Spatial Databases* (London; New York: Taylor & Francis, 1989).

[37] Rice et al., *Crowdsourced Geospatial Data: A Report on the Emerging Phenomena of Crowdsourced and User-Generated Geospatial Data*.

[38] Rice et al., *Crowdsourcing to Support Navigation for the Disabled: A Report on the Motivations, Design, Creation and Assessment of a Testbed Environment for Accessibility*.

ards and approaches are used in industry. The National Map Accuracy Standards (NMAS), developed in the early 1940s and published in 1947, are applicable to printed and fixed-scale maps. They specified that 90% of positional errors for easily identified features should be 1/30 of an inch at map scale for maps produced at a scale of 1:20000 or larger (more detailed), and 1/50 of an inch for maps produced at a smaller (less detailed) scale.[39] A more relevant contemporary approach for assessing accuracy is the National Standard for Spatial Data Accuracy (NSSDA), which uses statistical methodology for estimating the positional accuracy of maps and geospatial data.[40] There is no single threshold value, as in the NMAS, but federal agencies that produce, collect, or use geospatial data are encouraged to set their own standards for acceptable accuracies and report accuracies using the methodology outlined in NSSDA. The NSSDA uses the root-mean square error statistical error measure (RMSE), which is the square root of the average squared deviations of sampled points from a source of ground truth. The results of the NSSDA-based positional accuracy assessment are reported using a 95% confidence interval, which implies that less than 5% of observations will have a positional error greater than the reported error confidence limits. The NSSDA acknowledges that geospatial datasets typically have multiple layers, each with its own characteristics, and possibly, differing accuracies. For complex, composite datasets with multiple input layers, the NSSDA suggests:

1. If data of varying accuracies can be identified separately in a dataset, compute and report separate accuracy values.
2. If data of varying accuracies are composited and cannot be separately identified AND the dataset is tested, report the accuracy value for the composited data.
3. If a composited dataset is not tested, report the accuracy value for the least accurate dataset component.[41]

In the GMU Geocrowdsourcing Testbed, positional accuracy is assessed for each individual report contributed to our system, and in this way, our

[39] "United States National Map Accuracy Standards" (U.S. Bureau of the Budget, 1947), http://nationalmap.gov/standards/pdf/NMAS647.PDF; "National Geospatial Data Standards - United States National Map Accuracy Standards," *USGS*, October 28, 2011, http://nationalmap.gov/standards/nmas.html; Paul A. Longley et al., *Geographic Information Systems and Science*, 3rd edition (Hoboken, New Jersey: John WIley & Sons, 2011). §6.3.3, p.164.

[40] U.S. Geological Survey, "Geospatial Positioning Accuracy Standards, Part 3: National Standard for Spatial Data Accuracy," *Federal Geographic Data Committee*, August 19, 2008.

[41] Rice et al., *Crowdsourced Geospatial Data: A Report on the Emerging Phenomena of Crowdsourced and User-Generated Geospatial Data*. Chapter 4, p. 67.

approach is most similar to NSSDA condition one, where separate accuracy values can be obtained and reported.

Positional accuracy studies have been conducted for crowdsourced geospatial data, primarily by comparing OpenStreetMap (OSM) data to a source of known, higher accuracy. The results of these studies are summarized in Ruitton-Allinieu (2011).[42] Haklay's 2010 study of OSM data in the United Kingdom[43] demonstrated that the positional accuracy of OSM roads data, when compared to authoritative Ordnance Survey data, was within six meters. Girres et al. (2010)[44] performed a quality assessment of the French OSM datasets with similar findings. They addressed a comprehensive set of quality measures, including positional (geometric) accuracy, attribute accuracy, completeness, logical consistency, semantic accuracy, temporal accuracy, lineage, and usage. With regard to positioning of features in their sample, they determined that the Euclidean distance between matching intersection points in the road networks averaged 6.65 meters, with a maximum of 31.58 meters and a minimum of 0.68 meters.

In the GMU Geocrowdsourcing Testbed (Rice et al. 2013), positional accuracy assessments (and all other quality assessments) are done by moderators for the individual reports contributed to our system, which are then used to create obstacles. These report-level quality assessment statistics are inherited by the obstacles during the obstacle creation process, and are a direct reflection of the quality of the source report(s). In general, all the quality statistics and quality assessment practices for reports also apply to the obstacles generated from the reports.

The positional accuracy characteristics of the reports in our GMU Geocrowdsourcing Testbed are determined from a comparison of the contributor's position estimate, derived from the positioning of an icon on the map, and the moderator's field-checked position for the report. The difference between these positions is calculated with spherical formulas and converted to meters. The median positional accuracy for our reports is 2.236 meters, and the average positional accuracy is 18.36 meters, with a standard

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[42] Anne-Marthe Ruitton-Allinieu, "Crowdsourcing of Geoinformation: Data Quality and Possible Applications" (Master of Science, Aalto University, 2011), http://maa.aalto.fi/fi/geoinformatiikan_tutkimusryhma-gma/geoinformatiikka_ja_kartografia/2011_ruitton-allinieu_a.pdf.

[43] M. Haklay, "How Good Is Volunteered Geographical Information? A Comparative Study of OpenStreetMap and Ordnance Survey Datasets," 2008.

[44] Girres and Touya, "Quality Assessment of the French OpenStreetMap Dataset."

deviation of 75.36 meters. The minimum positional error in our testbed is 0, while the maximum positional error is 447.76 meters. This large average positional error for reports (18.36 meters) is strongly influenced by two reports with unusually high positional errors (322.86 meters and 447.76 meters). In these two cases, the report contributor failed to reposition the blue location icon (close to the centers of Figure 6, Figure 7, and Figure 8) from its default location, resulting in large positional errors. Without these two reports included, the average positional error of reports in our system is 4.59 meters and median positional error is 1.86 meters. To avoid errors of this type in the future, we changed the default behavior of our contribution system and now require contributors to reposition the blue location icon before reports can be submitted. The recently updated mobile report contribution tool uses the device GPS for report positioning and should eliminate positional errors due to incorrect positioning of the location icon.

## Quality Assessment: Temporal Accuracy

Zook et al. (2010),[45] as well as Goodchild and Glennon (2010),[46] review the use of crowdsourced geospatial data during natural disasters, where the primary focus is on rapid data collection. Goodchild and Glennon's discussion of the community mapping efforts during the California wildfires and Zook et al.'s discussion of similarly rapid mapping efforts during the Haitian earthquake, contrast with the much longer production processes for authoritative data. These two paradigms are compared in Chapter 2 of Rice et al. (2012a).[47] Zook (2010), in particular, notes the value in combined or hybrid uses of CGD and authoritative data used during the Haitian earthquake.

Many of the devices used for crowdsourced geospatial data capture (smartphones, tablets, GPS, cameras, etc.) have the ability to capture time, and an acquisition time-date stamp is often embedded within the data. Temporal quality in geospatial data is related to the accuracy of time measurements contained in the data, and importantly (from the perspective of CGD), the update frequency for the dataset. Update frequency is

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[45] Zook et al., "Volunteered Geographic Information and Crowdsourcing Disaster Relief."

[46] Michael F. Goodchild and J. Alan Glennon, "Crowdsourcing Geographic Information for Disaster Response: A Research Frontier," *International Journal of Digital Earth* 3, no. 3 (September 2010): 231–41, doi:10.1080/17538941003759255.

[47] Rice et al., *Crowdsourced Geospatial Data: A Report on the Emerging Phenomena of Crowdsourced and User-Generated Geospatial Data*. P. 7-18

important for CGD, due to the speed with which CGD can be collected. In past decades, authoritative geospatial data production cycles could take years and typically ended with a paper map printed on a specific date. The production cycles for CGD are more continuous in nature, characterized by frequent updates and immediate availability over computer networks. During three-month period in 2009, Girres et al.[48] noted a 31.7% increase in OSM features, representing 260,000 objects. For France, they noted a positive linear relationship between the number of contributors present, the number of objects in OSM, and the frequency of updates, validating the Linus' Law[49] concept for CGD noted in a separate publication by Haklay (2010).[50]

For our approach to temporal accuracy, we are interested not just in the accuracy of individual time measurements associated with observation and report submission times, but also in the elapsed time between the start and end of an obstacle or event "lifespan", which is a more significant aspect for the transient obstacles and events. Future efforts will focus on identifying the precision for estimates of start and stop times of transient obstacles.

## Quality Assessment: Attribute Accuracy

Attributes, in a geospatial sense, are the non-spatial data linked to a location. Attributes describe the characteristics of a geospatial feature and can include anything from measureable characteristics, like length and width, to descriptive characteristics, like ownership or land cover. According to Girres et al. (2010), attribute accuracy "assesses the accuracy of quantitative attributes, the correctness of non-quantitative attributes and the classification of features."[51]

Our GMU Geocrowdsourcing Testbed does not ask contributors for direct measurements or assessments of the quantitative attributes of an obstacle, but it does request that users provide estimates of duration and urgency,

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[48] Girres and Touya, "Quality Assessment of the French OpenStreetMap Dataset."

[49] Eric S. Raymond, "Release Early, Release Often," *The Cathedral and the Bazaar*, 08/02, http://www.catb.org/esr/writings/homesteading/cathedral-bazaar/ar01s04.html.

[50] Mordechai (Muki) Haklay et al., "How Many Volunteers Does It Take to Map an Area Well? The Validity of Linus' Law to Volunteered Geographic Information," *Cartographic Journal, The* 47, no. 4 (November 1, 2010): 315–22, doi:10.1179/000870410X12911304958827.

[51] Girres and Touya, "Quality Assessment of the French OpenStreetMap Dataset." p.440.

both of which involve ordinal category selections, and a categorical selection of an obstacle type, which is a descriptive characteristic.

Feature naming in geospatial datasets is a difficult area for quality assessment, due to the lack of universally accepted naming conventions. Girres and Touya analyzing the names assigned to lakes in OSM and comparing them to names recorded in BD Topo®, produced by the French National Institute of Geographic and Forestry Information (IGN), Girres et al. found that 55% of the lake names matched. A main finding in the Girres et al. study, reflecting the concept of Linus' Law, is that the more contributors there are for a given area, the better the quantitative attribute accuracy. They suggest a linear relationship between the number of quantitative tags recorded for data for a given area and the number of contributors. Haklay et al. (2010) [52] suggest a similar dynamic with regard to positional accuracy of features in OSM.

Errors due to misclassification and incorrect attribute values are common in CGD. If an attribute specification is available, this problem may be due to the contributor's inability to correctly assign the appropriate attribute. In some cases, assignment of an appropriate attribute value may be subject to interpretation, where even experts might disagree. In other cases, attribute accuracy problems may be due to a lack of expertise on the part of the contributor, who may lack the technical background and experience required to understand and assign an appropriate value.

## Other Quality Assessment Considerations

### Completeness

As noted in Girres et al. (2010),[53] completeness measures the absence of features (omissions) in a dataset, and the existence of superfluous features (commissions) in a dataset. Completeness is often discussed in the context of a dataset's specification, which is the selection criteria and expected level of detail at a specific scale. CGD projects often lack a specification at their outset, and therefore it is difficult to determine completeness. Coverage, which describes a different but related aspect of quality, assesses the presence and density of features found in an area. Coverage can be assessed without a specification by comparing a dataset with an authorita-

[52] Haklay et al., "How Many Volunteers Does It Take to Map an Area Well?"

[53] Girres and Touya, "Quality Assessment of the French OpenStreetMap Dataset."

tive source at the same general scale and same level of detail (Haklay 2010, Girres et al. 2010). Haklay (2010)[54] assessed the coverage of roads in OSM and determined that they had 69% coverage in comparison with the authoritative datasets. A 2008 study by the same author noted much higher coverage in affluent areas (76.6%) than in poor areas (46.1%).[55]

Rice et al. 2013 assessed the initial coverage of the GMU Geocrowdsourcing Testbed (2013, 38) noting four conspicuous data voids in the West Campus, Mason Inn, Patriot Center, and Masonvale areas (Figure 6). Our engagement with neighboring jurisdictions Fairfax City and Fairfax County has resulted in an expanded area of interest and new data voids (Figure 7), which are being assessed on a weekly basis to increase our coverage. Data voids could be due to the lack of obstacles or lack of observations in an area. In our case, we believe the voids are due to lack of observations in those areas.

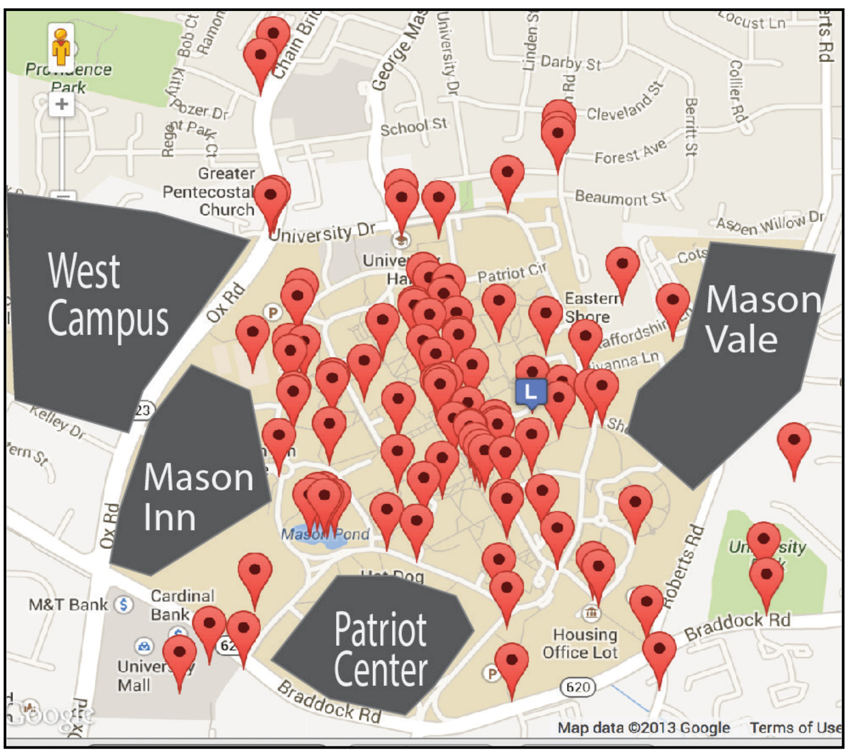


Figure 6. Geographic reporting voids (2013)

54 Haklay, “How Good Is Volunteered Geographical Information?”

55 Ibid.

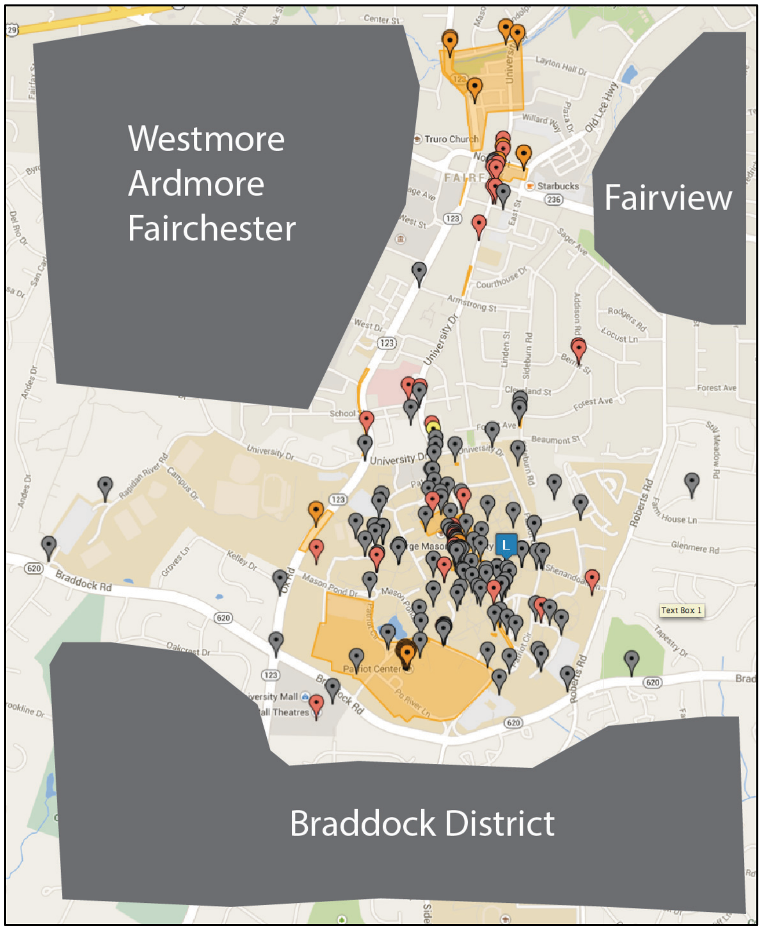


Figure 7. Geographic reporting voids (2014)

## Malicious and Mischievous Content

Wikipedia is the most popular reference website in the world, and one of the most targeted, with respect to malicious content and vandalism. OSM, the most widely used geocrowdsourcing resource, has similar problems with malicious and mischievous content. Both resources have developed extensive, automated tools to detect unusual patterns and transactions that are out of the ordinary, in an effort to reduce malicious and mischievous content. Although Rice (2001, 2005)[56,57] notes some significant exceptions with regard to cartographic copyright traps, false content in geospatial data can reduce the utility of CGD and the perceived quality. Malicious and mischievous content also discourages large, publicly ex-

[56] Matthew T. Rice, "Strategies for Robust Digital Cartographic Steganography," in *Proceedings, The 20th International Cartographic Conference, ICC2001, Beijing, China, August*, 2001, 1156–64.

[57] Matthew T. Rice, "Intellectual Property Control for Maps and Geographic Data" (Ph.D. Dissertation, University of California, 2005).

posed organizations from using CGD or related techniques, due to the legal liabilities and potential embarrassment. Rice et al. (2012a)[58] discusses this topic in more detail. For this project, the two items of potential malicious and mischievous content are inappropriate or unauthorized image content, and profanity, both of which would reflect negatively on the authoritative partners and project staff. At this point we are not seeing either of these items in our contributions, but have technical safeguards for profanity detection, which are discussed later in this chapter.

### Logical Consistency

Logical consistency refers to the use of tests for validity of CGD, and includes items such as common digitizing errors (undershoots, overshoots, sliver polygons, etc.), topological errors, such as unconnected network segments or segments that do not properly intersect, as well as data values that are out of range. Longley et al. (2011, 240) contains a useful summary of the common topological errors. OSM has developed some automated tools for identifying topological errors in their data, and researchers Goodchild and Li (2012) recommend a geographic rules-based approach for determining the validity of CGD.[59] This rules-based approach for addressing logical consistency is also discussed in Rice et al. (2012a, 73-75). As discussed later in this chapter, assessing logical consistency for the data contributed to our system consists primarily of a check for valid data values during the reporting process. The underlying geospatial data used for routing in our testbed is checked for logical errors with inspection of undershoots, overshoots, and overlapping features being the primary focus.

### Risk and Fitness for Use

For geospatial information, the weight and consideration given to quality is also often based on the risks associated with its use. If quality is known, the user can weigh the risk of use and reason through scenarios where errors could occur. Goodchild and Glennon's discussion of the crowdsourcing dynamics during the Santa Barbara wildfires describes this dilemma.[60] As the wildfire moved through the Santa Barbara area and the neighborhoods evacuated, residents had to carefully weigh the risk of elective evac-

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[58] Rice et al., *Crowdsourced Geospatial Data: A Report on the Emerging Phenomena of Crowdsourced and User-Generated Geospatial Data*.

[59] Michael F. Goodchild and Linna Li, "Assuring the Quality of Volunteered Geographic Information," *Spatial Statistics* 1 (May 2012): 110–20, doi:10.1016/j.spasta.2012.03.002.

[60] Goodchild and Glennon, "Crowdsourcing Geographic Information for Disaster Response."

uation, with its extreme stress, discomfort, and dislocation, with the risk of staying in place (possible injury or death).[61] The use of crowdsourced information in this scenario and others often involves a rapid assessment about the dangers of accepting asserted information. While in statistical science this assessment is contained within the probabilistic domain of a significance test and type I and type II errors, in most scenarios the assessment is done through instinct, experience, and trust. Because we moderate all obstacle reports to our system, we consider the risk for possible harm from this information to be very low.

## Methods and alternatives for quality assessment

A foremost concern about the use of crowdsourced geospatial data, as noted in Rice et al. 2012a,[62] is quality. Goodchild and Li (2012)[63] identify three principal methods for quality assurance:

1. The **crowdsourced approach**, based on Linus' Law where the regular contributors and public at large will find and correct errors. Goodchild and Li (2012, 114) suggest this approach works well for prominent geographic features but not as well for obscure ones, which gather fewer "eyes" to catch and correct errors. Very large projects such as OSM with an active user base can make this approach work.[64]
2. The **social approach** relies on a hierarchal structure of trusted individuals to act as moderators and gatekeepers.[65] The moderators tend to be the contributors with the most experience and history of contributions. Characteristic of this approach, Mooney and Corcoran noted the same asymmetric contribution patterns seen in Wikipedia, where a very small proportion of the user base contributes a majority of the edits.[66,67,68]

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[61] Ibid.

[62] Rice et al., *Crowdsourced Geospatial Data: A Report on the Emerging Phenomena of Crowdsourced and User-Generated Geospatial Data*.

[63] Goodchild and Li, "Assuring the Quality of Volunteered Geographic Information."

[64] Ibid. P. 114.

[65] Ibid.

[66] Rice et al., *Crowdsourcing to Support Navigation for the Disabled: A Report on the Motivations, Design, Creation and Assessment of a Testbed Environment for Accessibility*.

[67] P. Mooney and P. Corcoran, "Accessing the History of Objects in OpenStreetMap," in *Proceedings of the 14th AGILE International Conference on Geographic Information Science, Utrecht, The Netherlands, Eds: Stan Geertman, Wolfgang Reinhardt and Fred Toppen P*, vol. 141, 2011.

[68] Peter Mooney and Padraig Corcoran, "Using OSM for LBS – An Analysis of Changes to Attributes of Spatial Objects," in *Advances in Location-Based Services*, ed. Georg Gartner and Felix Ortag, Lecture Notes in Geoinformation and Cartography (Springer Berlin Heidelberg, 2012), 165–79, http://dx.doi.org/10.1007/978-3-642-24198-7_11.

3. The **geographic approach**, where geocrowdsourced contributions are matched against known geographic facts and known geographic context in which the facts occur. Inconsistencies emerge when asserted contributions conflict with known principles and rules.

## Our Approach to Quality Assessment

The GMU Geocrowdsourcing Testbed relies on the **social approach** for quality assessment, using a small team of experienced moderators to check, validate, and provide ground truth for all reports contributed to our system.

As described in the previous chapter, the reports contributed to our system receive a comprehensive quality assessment, encompassing all of the critical elements of the "atomic view" of geographic information, discussed in Longley et al. (2011), where geographic data is composed of three components: location, time, and attribute. Our moderators check and assess these elements and produce quality assessment metrics for position, time, and attribute. The quality assessment metrics are combined into a single quality assessment score that provides a comprehensive metric for each report. The next step in our system is the generation of obstacles, which involves identifying any clusters of reports associated with the same transient event, and using them to create an obstacle. The most frequent pattern in our current system is to generate an obstacle from a single report, and this involves using the characteristics of the report, including its quality assessment, as the default attributes for the obstacle.

Although our moderation-based approach reduces the risk of erroneous reports, it is resource intensive. It requires daily time and effort, and the regular attention of five students, who validate and check reports in the field and then provide the quality assessment. A project consultant and subject matter expert suggested that if the financial resources that support moderation activities are reduced for any reason, we consider implementing alternative strategies for quality assessment, such as those mentioned by Goodchild and Li.

What would be required to switch to another method of quality assessment? Clearly, we would benefit from a greatly expanded community of contributors, which could be recruited through the same type of social activities (mapping parties) that has become an important part of OSM's success. Harnessing the altruism and social rewards associated with contribution has been shown to be effective in similar crowdsourcing projects as noted by Borst (2010), Coleman et al. (2010), Rogstadius et al. (2011), and Zhang et al. (2006).[69,70,71,72] In the future, with a much larger contributor base and with sufficient interaction from authoritative elements, we will be able to change our approach and follow the general advice contained in Goodchild and Li (2012) by having some of this information generated by other contributors.

The development of our moderation workflows and processes is addressed in Rice et al. (2013),[73] Paez (2014),[74] and Pease (2014).[75] Using the framework of our quality assessment sub-data model and associated workflows outlined in Rice et al.,[76] our team of moderators perform a set of daily tasks to ensure reports contributed to our system are reviewed and checked for quality. These tasks will be reviewed in the context of quality assessment parameters discussed in the previous section.

### Moderating position

The reported location of an obstacle in our GMU Geocrowdsourcing Testbed is currently determined by placement of a locator icon, which can be click-dragged around the map (Figure 8). A contributor positions the icon relative to familiar buildings and features, and can reposition the icon during the report submission process. The positional accuracy of the report depends on both the knowledge of the location of the obstacle and the ability of the contributor to place the icon on the intended location. The

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69 Irma Borst, "Understanding Crowdsourcing: Effects of Motivation and Rewards on Participation and Performance in Voluntary Online Activities" (PhD Series, Erasmus University Rotterdam, 2010).

70 D. Coleman, B. Sabone, and J. Nkhwanana, "Volunteering Geographic Information to Authoritative Databases: Linking Contributor Motivations to Program Characteristics," *Geomatica* 64 (2010): 27–40.

71 J. Rogstadius et al., "An Assessment of Intrinsic and Extrinsic Motivation on Task Performance in Crowdsourcing Markets," in *Proceedings of the Fifth International AAAI Conference on Weblogs and Social Media: Barcelona, Spain*, 2011.

72 Xiaoquan Zhang and Feng Zhu, "Intrinsic Motivation of Open Content Contributors:the Case of Wikipedia," *Workshop on Information Systems and Economics*, 2006.

73 Rice et al., *Crowdsourcing to Support Navigation for the Disabled: A Report on the Motivations, Design, Creation and Assessment of a Testbed Environment for Accessibility*.

74 Fabiana I. Paez, "Recruitment, Training, and Social Dynamics in Geo-Crowdsourcing for Accessibility" (Master of Science, George Mason University, 2014).

75 Patricia A. Pease, "The Influence of Training on Position and Attribute Accuracy in VGI" (Master of Science, George Mason University, 2014).

76 Rice et al., *Crowdsourced Geospatial Data: A Report on the Emerging Phenomena of Crowdsourced and User-Generated Geospatial Data*. P. 28-40.

future use of GPS-derived coordinates through a mobile contribution interface will mitigate the problems with icon-based positioning, as discussed previously with selected reports showing high positional errors.

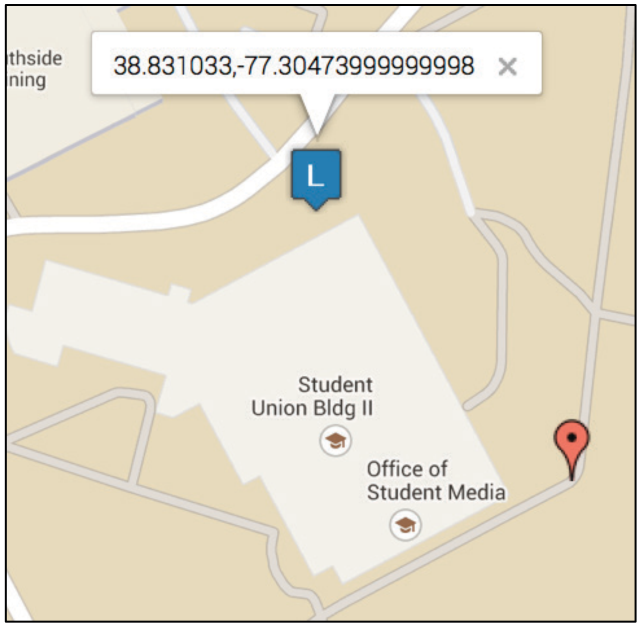


Figure 8. Locator icon for positioning reports

During the moderation process, moderators perform a field check of the submitted report location and provide an updated or corrected position using the same tools. Latitude and longitude values are recorded for the original report positioning and the moderator's corrected positioning, and the distance in meters between the two positions is calculated using spherical formulas and stored in a field titled qa:positional_accuracy.

As noted previously, the reports contributed to our system are moderated, quality assessed, and then used to create obstacles, which inherit the quality measures of the source report(s), including positional accuracy. Figure 9 shows the distribution of positional accuracy statistics for obstacles in our system.

The positional accuracy for reports and obstacles in our system is at the present time only visible to the moderators and project staff. The moderator's "ground truth" for position replaces the contributor's estimate for report position, but the difference between the two values is stored and the original values are retained. As a future extension of our work, we will be analyzing the expertise of our moderators to establish a "ground truth" position, which will provide a realistic estimate for our lower bound on positional error.

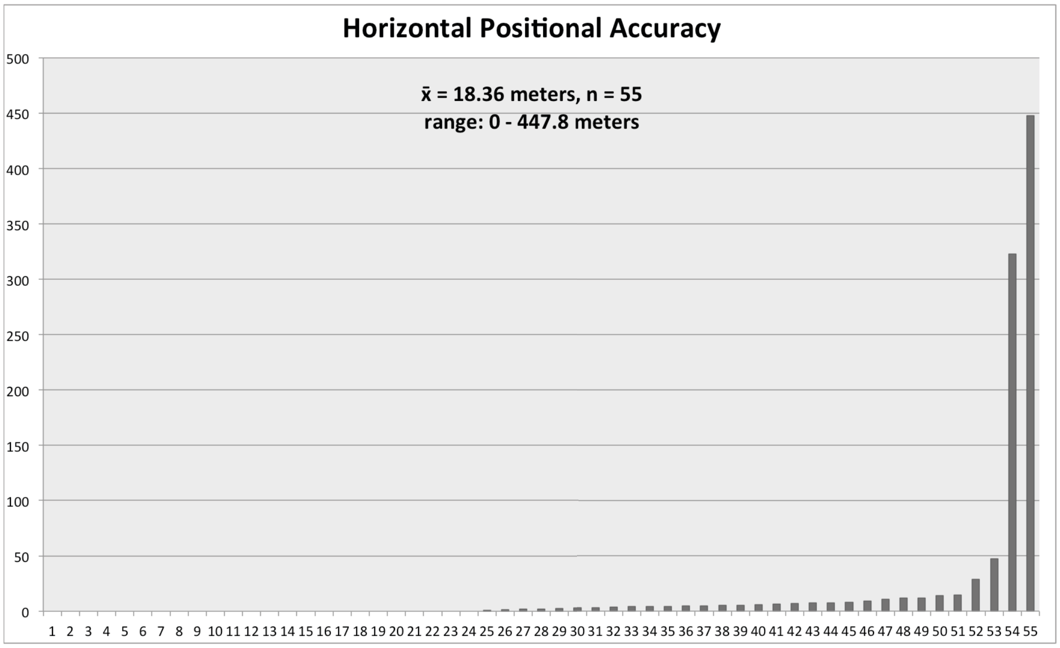


Figure 9. Horizontal Positional Accuracy for obstacles in our testbed (in meters)

A quality assessment statistic titled qa:location is generated by performing a two-step inverse transformation of the positional accuracy field. This procedure scales the positional accuracy field to values between 0 and 1. Reports that are (nearly) perfectly positioned relative to the moderator's ground truth (with a positional accuracy value between 0 and 1) receive a value of 1 for qa:location. Reports with a positional accuracy value greater than 1 receive a simple inverse transformation. In this case, a report with a positional accuracy of 100m would be inverse transformed and receive a value of 0.01. Figure 10 shows the corresponding inverse transformed values shown in Figure 9. Positional accuracy and qa:location figures are calculated, stored, and retained for every report and obstacle in our testbed.

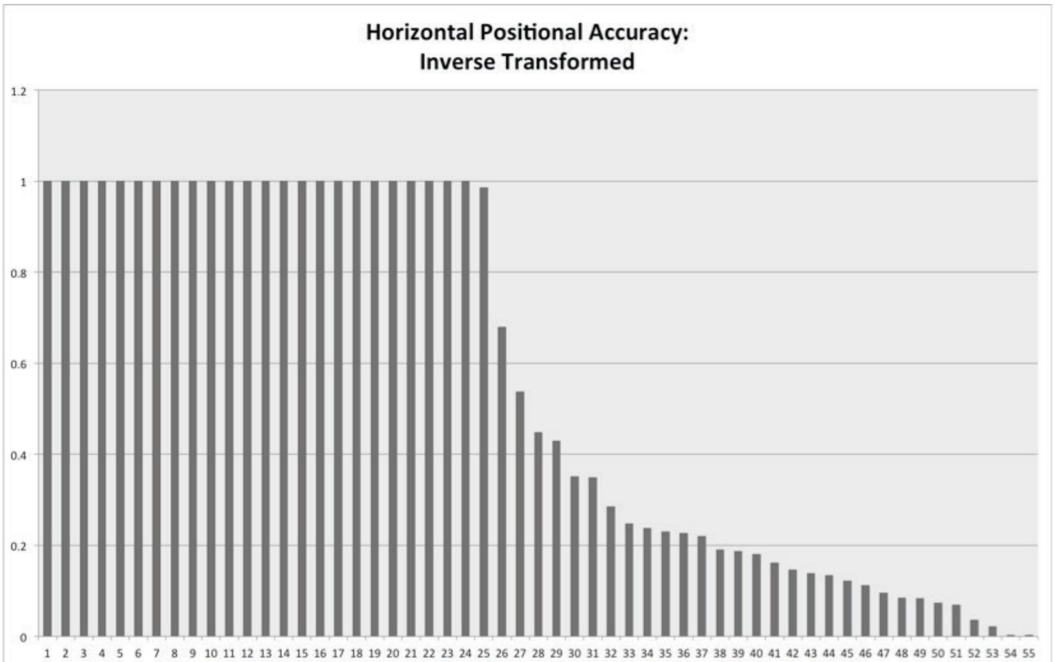


Figure 10. Inverse transformed horizontal positional accuracy for obstacles

Future quality statistics related to position will incorporate embedded geotags and azimuth information from submitted images, spatial footprints from geoparsed location text, and positioning derived from mobile device GPS.

## Moderating Temporal Consistency

Every report submitted to our system has two primary temporal characteristics: the time of report submission, captured directly by code in the testbed, and the time of observation, which is selected directly by the user through a JavaScript time/date picker that defaults to the contributor's current time. The difference in time is captured and stored as a variable with values of 1 (for a difference less than 24 hours) and 0 (more than 24 hours), and stored in a field titled qa:temporal_consistency. The choice of values (0,1) for the qa:temporal_consistency statistics (and other quality statistics) is done to facilitate the creation of composite numeric quality statistic. As with all of the other quality assessment items discussed in this chapter, all original temporal characteristics are preserved along with the derived quality assurance measures so that future modifications to our quality assessment process can be made, with values calculated or recalculated automatically.

### Moderating attributes: Location description

Contributors to our system are asked to provide a text-based description of the obstacle's location being reported. This description allows moderators to locate and verify reports, and provides a way of checking the consistency of position reporting. Moderators are responsible for correcting obvious misspellings and mistakes, but otherwise this field is left intact. The moderators do, however, provide a separate location description of their own, based on the original report location description. This moderated version of the location description is also stored with the report. Development of a detailed gazetteer and associated geoparsing capability (discussed in Rice et al. 2012b) will allow us to provide real-time footprints for text-based location descriptions. The presence of location text for a report is treated as a Boolean value and stored in a quality assessment field titled qa:location_text.

### Moderating attributes: Obstacle type

Contributors to our system tag their reports with an obstacle type using a multi-selection menu (Figure 11). Possible obstacle types are sidewalk obstruction, construction detour, entrance/exit problem, poor surface condition, crowd/event, and other. Moderators verify obstacle type using a field check and provide a moderator's version of the obstacle type.

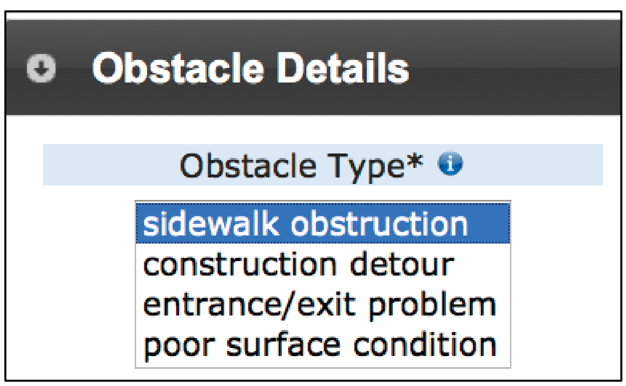


Figure 11: Obstacle type selection

This is stored in a field titled mod:obstacle_type and the categorical matching between the contributor's obstacle type and the moderator's obstacle type is stored as three possible values (0 = no match, 1 = partial match, 2 = exact match) in a field titled qa:obstacle_type. The choice of values for this statistic (0,1,2) is not based in theory but rather for the creation of a composite numerical quality statistic.

Moderating attributes: Obstacle description

Contributors provide a text-based description of each obstacle they report. Because the obstacle description text is publicly visible and disseminated through our website, this text field is checked for profanity and errors, and if necessary, corrected by moderators. If this field is edited, moderators are instructed to provide a concise, 80-140 character description of the obstacle, which is then stored in the moderator's obstacle description field.

Moderating attributes: Obstacle duration

Contributors provide their best estimate for how long a particular obstacle will be present. This duration estimate is selected from a menu with options Short (<1 day), Medium (1-7 days), and Long (>7 days), as seen in Figure 12.

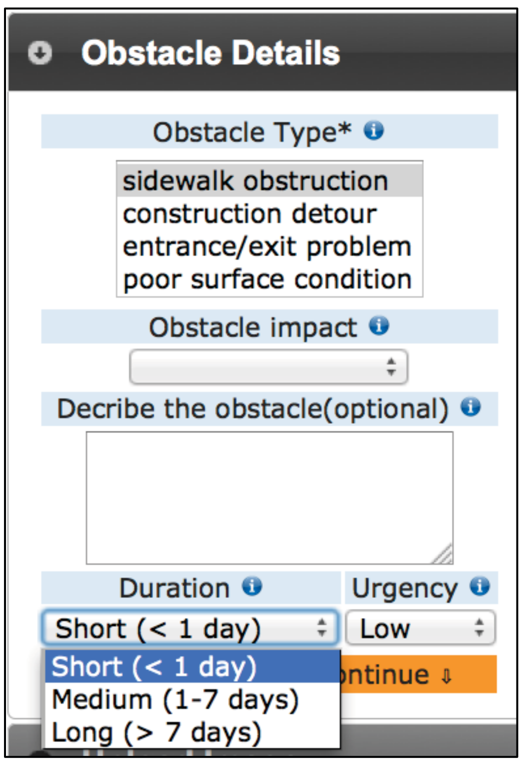

Figure 12. Obstacle duration selection

This duration estimate is checked by moderators and adjusted if necessary. The moderator's estimate for duration is stored in a separate field and a quality assessment statistic titled qa:duration is calculated and stored as an integer to reflect the quality of the match between the contributor's and moderator's estimate for this ordinal-level variable. The field qa:duration has a value of 0 for no match, 1 for a neighboring value match, and 2 for an exact match.

Moderating attributes: Obstacle urgency

A key field in our GMU Geocrowdsourcing Testbed is an obstacle's urgency, which is intended to be a reflection of the contributor's and moderator's assessment of how serious the obstacle is and what possible safety issues or danger it presents. Contributors select their best estimate for urgency using a pull-down menu (Figure 13), which has values for Low (representing a mere inconvenience), Medium (a moderate inconvenience and a possible safety hazard), and High (a significant inconvenience and a significant safety hazard).

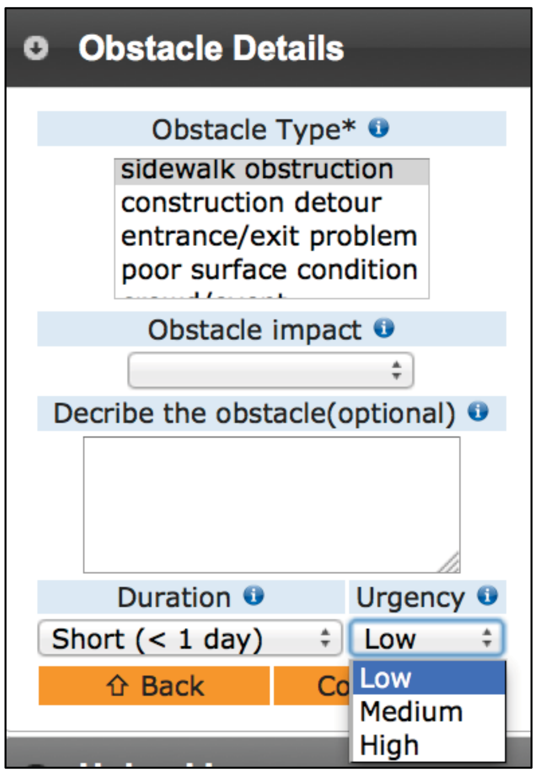

Figure 13: Obstacle urgency selection

Moderators are asked to carefully check the urgency estimate provided by the report contributor, and asked to provide an estimate of their own, based on standards decided upon collectively by the moderators. Similar to qa:duration, the match between the contributor's urgency estimate and the moderators urgency estimate is calculated and stored in a field titled qa:urgency. As with qa:duration, qa:urgency receives a value of 0 for no match, 1 for a neighboring category match, and 2 for an exact match. Future work will be done to assess the consistency of individual moderators in providing this attribute assessment as well as all other moderator-based decisions used for quality assessment.

### Moderating attributes: Images, feedback, and comments

Reports contributed to our system usually have images attached to them. Images are a very useful component of a report due to their use in verification of the obstacle and its location, and in many cases, disambiguation of the text-based obstacle description. Moderators check these images to ensure that they are appropriate and relevant. The quality of the images is assessed using established guidelines (Table 1) and a quality value and numerical score are assigned. A quality assessment statistic qa:image_quality is calculated and stored with the report. As with other moderator-derived quality statistics, future work will be done to assess the consistency of the individual moderators in making this assessment.

Table 1. Moderator Assessment Guidelines for Image Quality

| Guidelines for Image Quality Assessment | | |
|---|---|---|
| **Quality Rank** | **Score** | **Description** |
| **Missing** | 0 | **Image was not provided** |
| **Low** | 1 | **Image has multiple issues**<br>Photo does not fully encapsulate obstacle and does not provide a reference point for obstacle's location, or photo is blurry or of otherwise low quality that hinders ability to tell what the obstacle is or where it is located |
| **Medium** | 2 | **Image may have one issue but is useful has overall quality is good**<br>Photo may be missing a reference point to determine location (too zoomed in, no buildings in background), photo may be taken at night so it is difficult to see obstacle detail, or photo does not fully encapsulate obstacle |
| **High** | 3 | **Image has no barring issues**<br>Photo was taken during the day, not blurry, provides a reference point (such as a building), fully encapsulates obstacle |

Moderators also check the feedback and comments for each report, and can attach their own internal comments, which are saved with the report and viewable internally by all moderators and project staff. Feedback and comments are not required elements for report submission and are not included in the obstacle quality score calculations.

### Moderating malicious content

An automated PHP-based scripting tool searches all text-based fields in each report for profanity, and flags the reports that contain any entries from a list of offensive words and terms. This list is based on Google's blacklisted terms and has approximately 2000 entries. A Boolean moderator flag called MODFLAG is set to TRUE when an offending term is found. Report images, as mentioned previously, are checked for malicious or inappropriate content. Reports that have MODFLAG = TRUE because of profanity or for other reasons are not publicly displayed unless a moderator fixes the problem and resets the MODFLAG to false.

### Moderating logical consistency

As covered in the previous section, logical consistency is an important aspect of quality assessment and has a number of different manifestations. Girres (2010) describes logical consistency (using wording from Servigne et al. 2000)[77] as "the degree of internal consistency as modeling rules and specifications (including compliance with integrity constraints)."[78] Because our application has a specific geographic scope, and because we intend to provide relevant information and services to end-users within that geographic area, we screen all incoming reports for consistency. Reports must fall within the system boundaries, which are upper left: 38.861782, -77.346539 and lower right: 38.812844, -77.288174. When they fall outside the boundary, a Boolean variable called boundary_check is set to false. Reports with boundary_check = false are not displayed in the system, but can be modified and fixed by moderators. Moderators check the validity of content in all fields and when necessary, make changes.

[77] Sylvie Servigne et al., "A Methodology for Spatial Consistency Improvement of Geographic Databases," *GeoInformatica* 4, no. 1 (2000): 7–34.

[78] Girres and Touya, "Quality Assessment of the French OpenStreetMap Dataset." P. 440.

### Moderating completeness

Reports that are submitted to our system are given a composite score based on the number of fields that have valid entries. A report that is fully complete with valid entries in every field gets a score of 100%, while a report void of content receives a 0%. In practice, the GMU Geocrowdsourcing Testbed enforces valid data entry in several fields before submission can be completed, so completeness scores below 48% are not possible for successfully submitted reports. Moderators view the completeness score (called qa:completeness), but this calculation of the score is done automatically and stored with each report.

### Moderation: Summary measures

Moderators use all factors to assign a subject quality score to each report. qa:moderator_quality_score is an ordinal scale variable from 1 (very low quality) to 5 (very high quality), and is made based on written guidelines, training, and joint agreement. However, based on the broad coverage of this metric and its somewhat subjective nature, there have been concerns about moderator consistency in making this assessment. Assessing moderator consistency is of great interest as a future subject or study.

In computing our broadest and most all-encompassing composite final quality assessment score (discussed below and summarized in Table 2) the qa:moderator_quality_score was included as a factor and weighted heavily due to the perceived high value of this comprehensive assessment. Recent consideration has been made for the consistency of moderator assessments for this item, and the way that this moderator score might be contributing redundant content in our comprehensive composite quality scores. To look more closely at this issue, we assessed the relationship between this comprehensive moderator score, and the final quality score metric with this moderator score removed, which we refer to as quality assessment total score or in abbreviated form, qa:total_score. We expected to see a strong positive relationship between these two variables. Figure 14 shows the frequency of qa:moderator_quality_score for obstacles in our system, and Figure 15 shows the relationship between this comprehensive moderator score, and the quality assessment total score. Figure 15 indicates that there is no strong relationship between the qa:moderator_quality_score and qa:total_score. The dynamics of this relationship will be investigated in the next phase of our research. In future quality metrics for our testbed we will compute a total quality metric both with and without the contribution of the qa:moderator_quality_score.

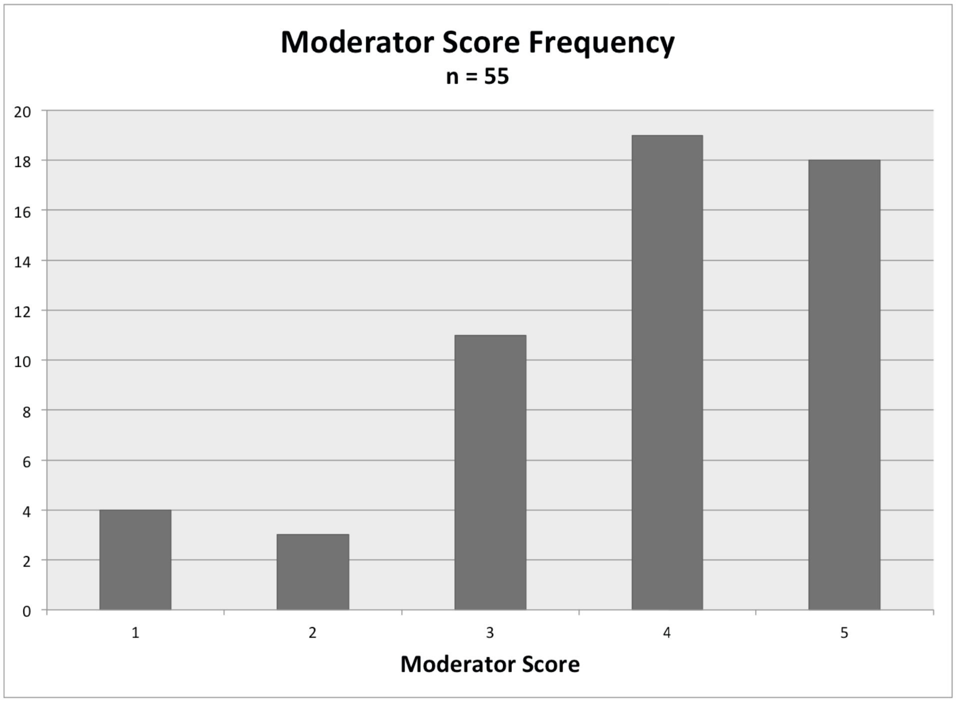


Figure 14. Moderator Score Frequency for testbed obstacles


Figure 15. QA:Total_Score by Moderator Score

## Moderation: Generation of a Final Quality Score

Once all the quality assessment tasks are finished and moderators have finished all moderation activities, a final quality metric is calculated. This quality metric is used with the other key quality metrics to provide our quality assessment. The final quality metric, titled qa:final_score, is a composite linear combination of all other quality assessment metrics, and has a range from 0 to 100. In practice, the quality scores for most reports vary between 55 and 95. The ranking and weighting of components for the qa:final_score is based on the mutual expert assessment of the moderator team, whose experience reviewing reports leads them to perceive certain quality assessment metrics as being more valuable than others. For instance, the quality of positioning (weighted at 17% and stored as qa:location) is perceived by the moderators to be a better indicator of the reports quality than the quality assessment statistics for the estimates for urgency and duration, which are weighted at 12% and 10%, respectively (Table 2). The weighting formula shown in Table 2 has changed several times and will continue to change as we refine our quality assessment metrics and discover which measures are most indicative of high quality. As noted, future quality assessment metrics will use a version of a comprehensive quality score that removes subjective moderator quality assessments, which are useful but may include redundancies.

Table 2. Quality Metric Calculations: Final Score

| Quality Assessment Variables | Values | RANKS | Weight (%) |
|---|---|---|---|
| QA: Temporal Consistency | 0,1 | 7 | 6 |
| QA: Location (X,Y) | Max = 1, Min = 0 | 2 | 17 |
| QA: Location text | 0,1 | 8 | 5 |
| QA: Image Quality | 0,1,2,3 | 3 | 15 |
| QA: Obstacle type | 0,1,2 | 5 | 11 |
| QA: Duration | 0,1,2 | 6 | 10 |
| QA: Urgency | 0,1,2 | 4 | 12 |
| QA: Completeness | 0-100 scaled to 0-1 | 9 | 4 |
| QA: Moderator Quality Score | 1-5 | 1 | 20 |
| | | | **100** |

### Moderation: Generation of Obstacles

After reports are moderated and receive quality scores, the moderator team generates obstacles from the reports, using a set of clustering tools to select similar reports and group them together. Each obstacle inherits characteristics from a template report, which is selected by the moderators and typically has the highest quality score. When multiple reports are clustered and used to generate an obstacle, a summary of the quality scores from the source reports is preserved along with the complete quality assessment from the template report. Obstacles are then generated and published to our website, which can display reports and obstacles depending on the viewer's preference. At present, we have no criteria for thresholding reports and removing any from consideration. The quality metrics we are developing will lead us, during the next phase of our research to analyze the influence of individual quality metrics and to assess the causes of both high and low scores. We also anticipate that quality scores will be a major factor in which reports are displayed and which are hidden from view, in areas and circumstances where multiple reports have been received for the same item.

Figure 16 and Figure 17 show the qa:final_score statistics for the 55 GMU Geocrowdsourcing Testbed obstacles collected between May 17, 2013 and

June 30, 2014, which were created from 221 reports. The scores for obstacles are ordered by submission date in Figure 16, and by qa:final_score in Figure 17. As can be seen in this graphic, quality scores for current obstacles vary between 55% and 95%. Our current testbed status as of September 4, 2014 indicates that we presently have 330 submitted reports and 90 obstacles generated from those reports.

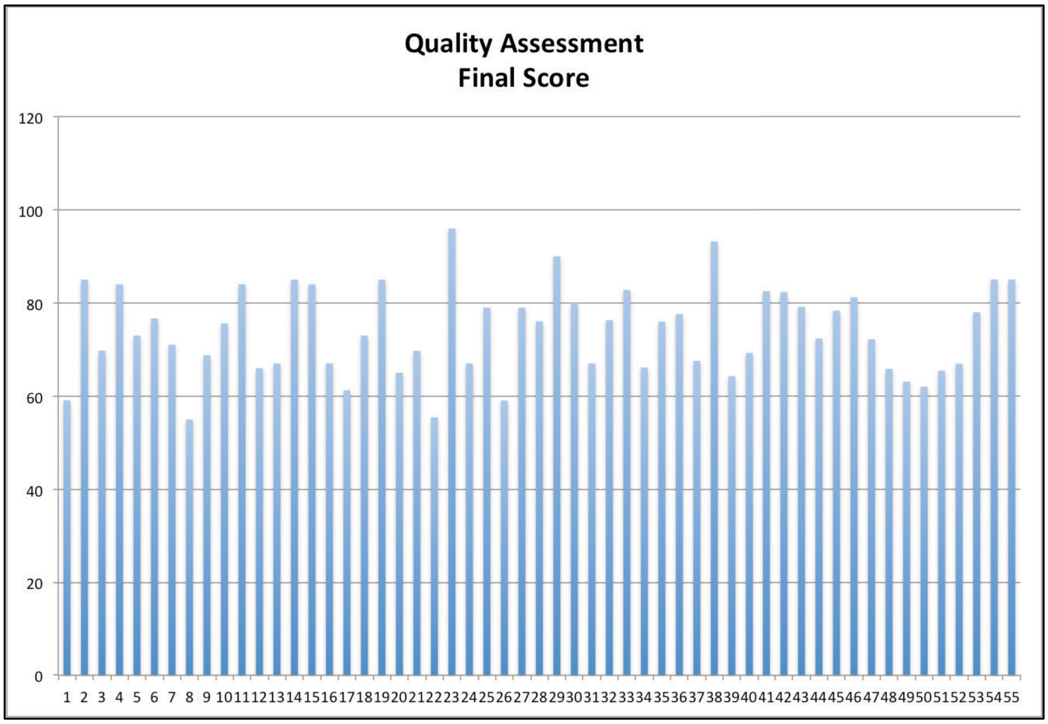


Figure 16. Quality assessment final scores for obstacles, sorted by submission date

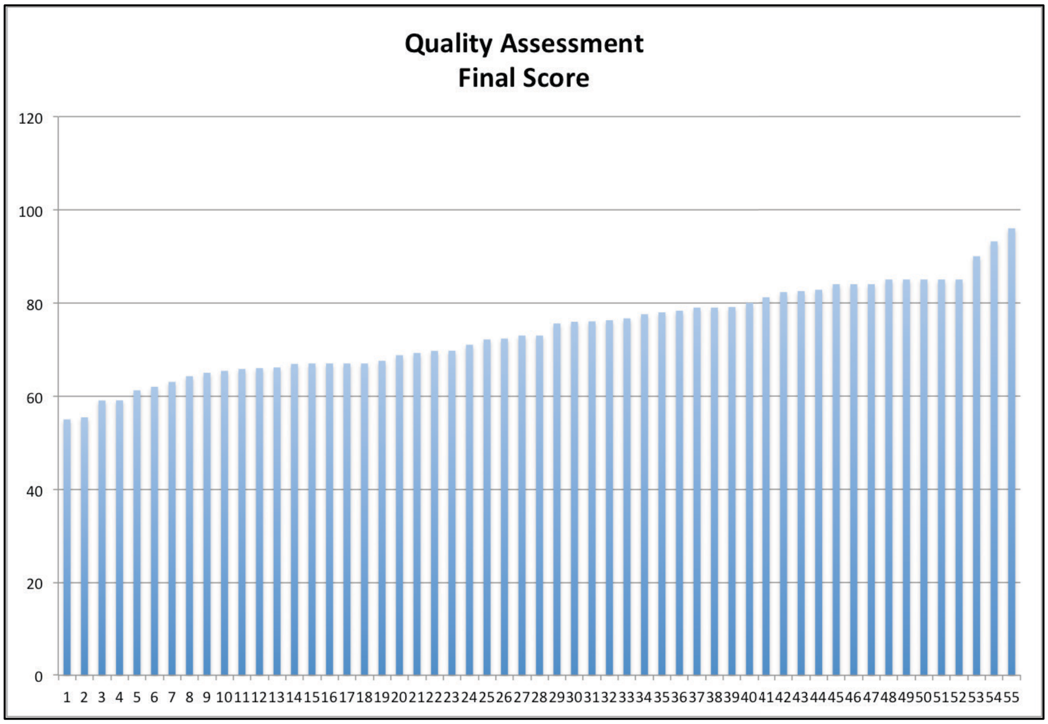


Figure 17. Quality assessment final scores for obstacles, sorted by score

Later in this report (Chapter 4) we look at different methods for visualizing information collected in the GMU Geocrowdsourcing Testbed, including graphics associated with the metrics described in this chapter.

The next chapter of this report (Chapter 3) looks at the creation of a training and recruitment program for contributors (Paez 2014)[79]. The significance of this research activity will be summarized with respect to quality assessment and the success of the GMU Geocrowdsourcing Testbed.

[79] Paez, "Recruitment, Training, and Social Dynamics in Geo-Crowdsourcing for Accessibility."

# 3 Recruitment and Training in the GMU Geocrowdsourcing Testbed

The emerging trend of geocrowdsourcing provides a cost-effective way to capture data that is often more accurate than authoritative data, as the local geographic knowledge that every individual carries with them provides the expertise required to contribute.[80] However, innate geographic knowledge is often not enough. An effective geocrowdsourcing system requires contributors who are trained and willing to participate. This chapter focuses on the dynamics of participation and how the recruitment and training of participants in our project influences quality.

## Origins of a Training and Recruitment System: Examples and Approaches

The work of Fabiana Paez, published April 2014 as a master's thesis, outlined the early phase of this project, where a comprehensive survey of geocrowdsourcing applications was conducted.[81] These applications (reviewed in the third chapter of Rice et al. 2012a[82]) were categorized by the activity involved: imaging, georeferencing, transcribing, digitizing, attributing, reporting, searching, tracking, validating, polling/surveying, socializing, and sharing. From the nearly 200 geocrowdsourcing projects and applications reviewed by Paez and research team member Brandon Shore, twenty-four projects and applications were chosen for detailed analysis, based on their prominence and ranking by project staff and collaborators at GMU and ERDC. From this analysis, Paez determined that more than half of the applications involved some type of basic contribution tracking, 20% of the projects incorporated a rating system for users or for contributions, 14% included some type of content restriction[83], and 26% of the projects involved some type of training for contributors (Figure 18).

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[80] Goodchild, "Citizens as Sensors: The World of Volunteered Geography"; Goodchild, "NeoGeography and the Nature of Geographic Expertise."

[81] Paez, "Recruitment, Training, and Social Dynamics in Geo-Crowdsourcing for Accessibility."

[82] Rice et al., *Crowdsourced Geospatial Data: A Report on the Emerging Phenomena of Crowdsourced and User-Generated Geospatial Data*.

[83] Waze, for instance, reserves the right in its Terms of Service to restrict content or delete any content it deems inappropriate and in Google Map's developer terms of service, certain business listings are subject to restrictions (https://developers.google.com/maps/terms ) [accessed Sep. 4, 2014].

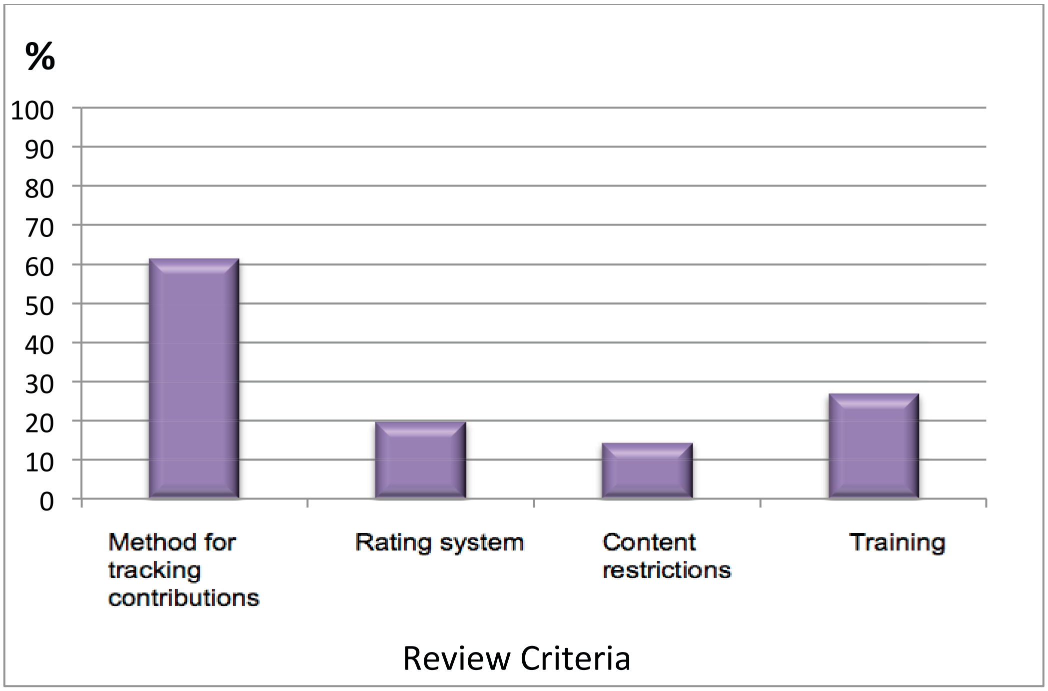


Figure 18. Proportion of surveyed geocrowdsourcing applications incorporating quality assessment characteristics, from Paez (2014). Used with permission.

Building on this comprehensive survey and analysis, Paez more closely analyzed the user training methods incorporated in Waze (a popular social traffic and navigation app),[84] OSM,[85] The National Map Corps (TNM Corps) of the U.S. Geological Survey (USGS),[86] and Google Map Maker.[87]

### Training: Waze

Waze is an extremely popular social traffic reporting and navigation app, with a reported user base of 50 million individuals.[88] Google acquired Waze in June 2013 for 1.3 billion dollars, in one of the largest and most notable high-tech acquisitions of the year. The application allows users to receive turn-by-turn navigation via GPS, but with the addition of location-specific updates of traffic load, traffic accidents, roadblocks, police checkpoints, and fuel prices. The app also allows users to report errors in the map database. Due to Waze's commercial/consumer orientation and its

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[84] "Waze - Social Traffic & Navigation App," accessed June 20, 2012, http://www.waze.com/.

[85] "OpenStreetMap," accessed April 28, 2012, http://www.openstreetmap.org/.

[86] "The National Map Corps," *USGS*, August 2, 2011, http://nationalmap.gov/TheNationalMapCorps/.

[87] "Google Map Maker," *Google*, accessed May 1, 2012, http://www.google.com/mapmaker.

[88] Josef Federman and Max J. Rosenthal, "Waze Sale Signals New Growth for Israeli High Tech," News, *Yahoo News*, (June 12, 2013), http://news.yahoo.com/waze-sale-signals-growth-israeli-high-tech-174533585.html.

use while driving, the interface is sparse and simple, and every function is achieved with a single finger tap on an icon. There is no training needed for the app, due to its simplicity and intuitiveness, but there are training elements associated with the map editor application. Through a few short videos, Waze explains the purpose and functionality of the mobile application, and how to edit the application's basemap. The basemap editor contains embedded video, which shows users step-by-step directions for editing while inside the application (Figure 19).

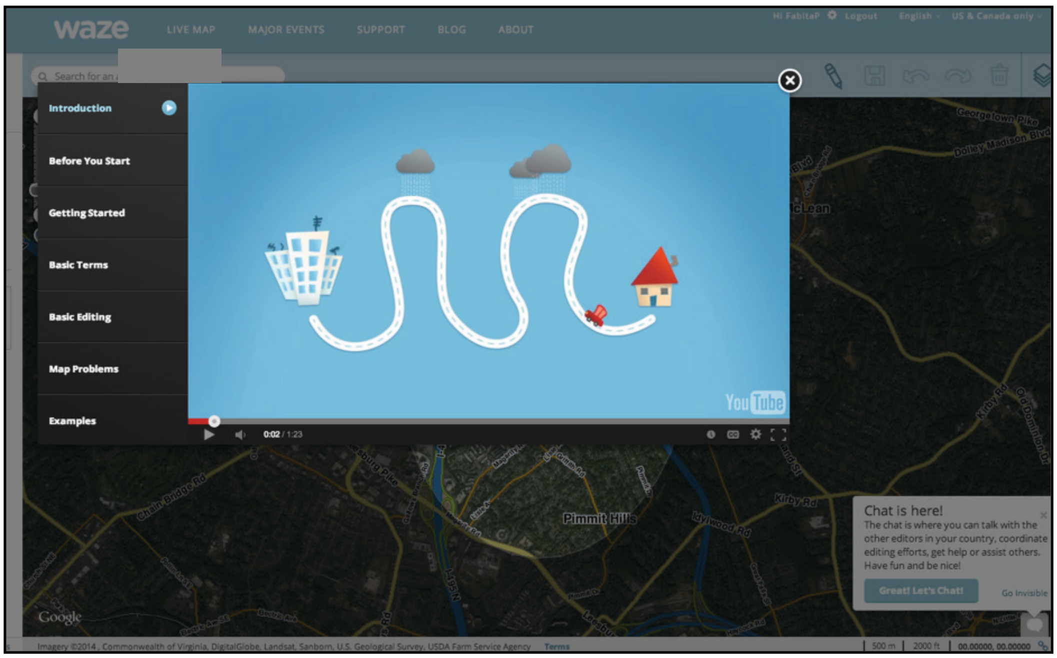


Figure 19. Waze Map Editor training video embedded in website

## Training: OpenStreetMap

Having a different profile than Waze (which was characterized as a simple tracking and reporting application in Paez 2014 and Rice et al. 2012a), OSM is a much larger and more ambitious application, or perhaps from some perspectives, a significant social movement and the centerpiece of the open source mapping world. Our previous report provided extensive descriptions of OSM from a variety of perspectives, but in our Chapter 3 analyses and in Paez (2014) it was characterized as a digitizing and validating application.

At its core, OSM is about generating high-quality basemaps and data for use in open-source applications. OSM provides a large number of tools and resources for learning how to edit its maps. After creating an account in OSM, users receive an introductory email providing a list of the resources where users can find training material, such as videos,[89] a wiki,[90] and a questions and answers site.[91] The training methods used in OSM vary in length and complexity according to the many ways to contribute data. In early 2014, OSM improved its training method for editing its map, which is now embedded in its website (Figure 20)[92]. The "Walkthrough" link takes the user to an interactive training module, which shows the different features available to edit the maps. As Figure 21 shows, while completing this optional training, a bar at the bottom of the page shows the users the sections that have been explained and the ones that have not been reviewed. This embedded training is similar in functionality to Waze.

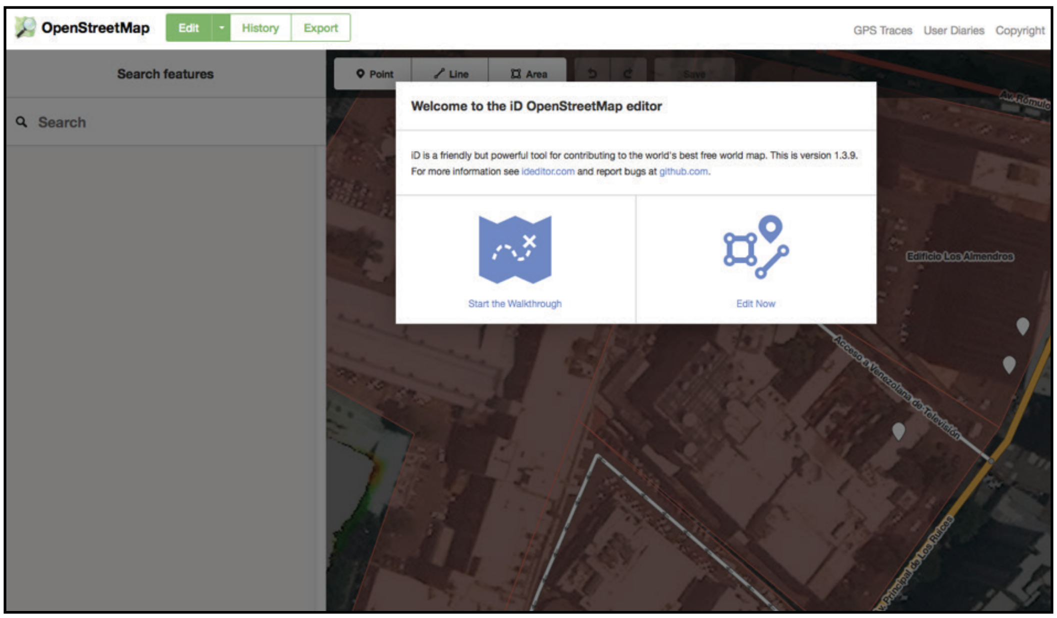


Figure 20. OSM edit tool with embedded training

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[89] Steve, "OpenStreetMap," *ShowMeDo*, 2008, http://showmedo.com/videotutorials/series?name=mS2P1ZqS6.

[90] "Beginners' Guide - OpenStreetMap Wiki," July 28, 2013, http://wiki.openstreetmap.org/wiki/Beginners%27_Guide.

[91] "OpenStreetMap Help Forum," accessed August 26, 2013, https://help.openstreetmap.org/.

[92] To view the embedded training video, see: https://www.waze.com/editor/?lon=-95.54538&lat=36.22089&zoom=0#tutorial-dialog [accessed Sep. 4, 2014]

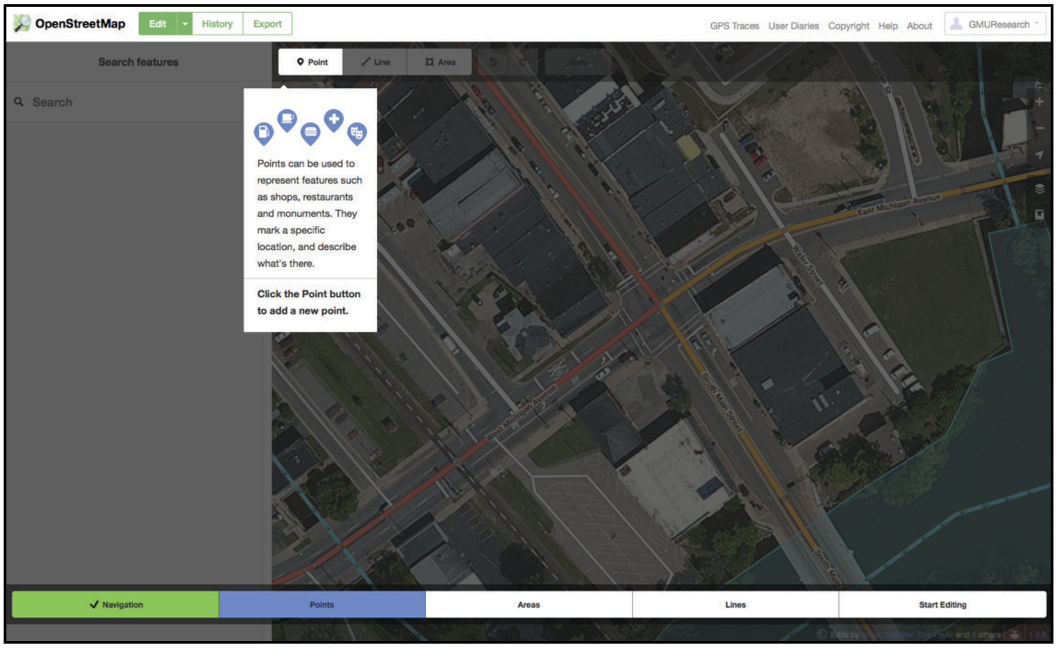


Figure 21. OSM edit-tool training material with bar showing training progress

Training: The National Map Corps (USGS)

TNM Corps is a program of the USGS, which involves crowdsourcing data collection applications where end-users can edit the National Map database.[93]. It was discussed in detail in our 2012 report[94] and is an important point-of-reference in looking at how one of the most important and revered authoritative government geospatial data producers is incorporating crowdsourcing into its map production workflows.

The training, developed as a part of the USGS TNM Corps program, teaches contributors how to execute editing tasks and is less interactive and dynamic than the ones provided by Waze and OSM. However, TNM Corps training material provides step-by-step, detailed instructions using simple terminology, concise information, and graphics of the map editor's interface. Figure 22 shows some sections of the TNM Corps training material, which describes some of the features in the map editor interface through static arrows and text.

[93] See https://my.usgs.gov/confluence/display/nationalmapcorps/Home [accessed Sep. 4, 2014]

[94] Rice et al., *Crowdsourced Geospatial Data: A Report on the Emerging Phenomena of Crowdsourced and User-Generated Geospatial Data.*

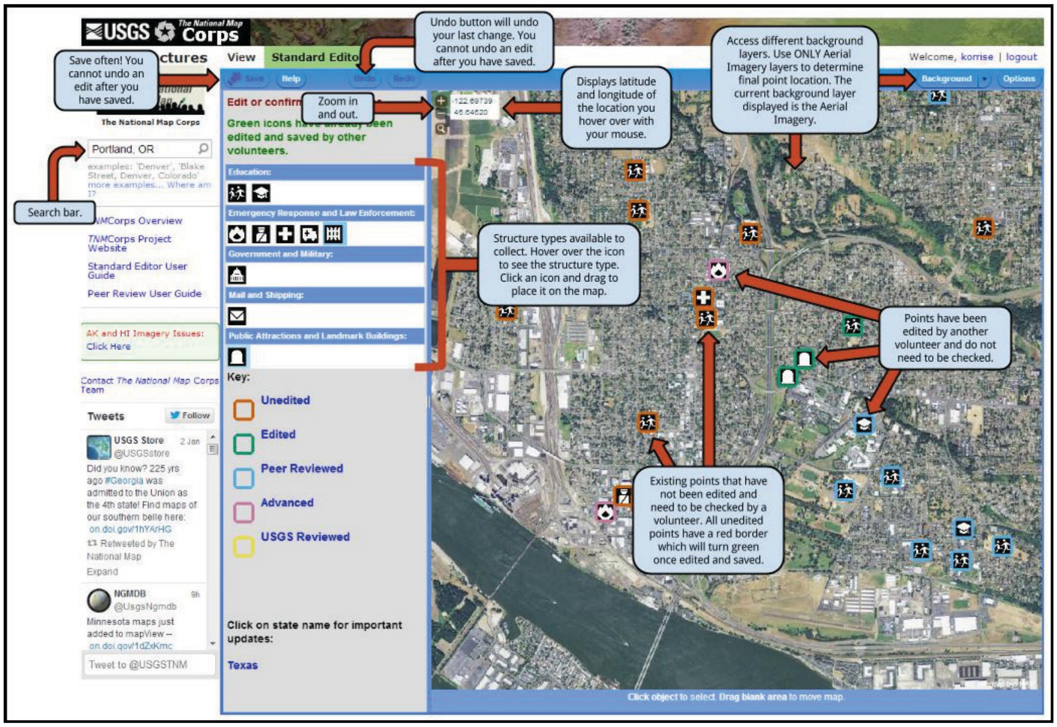


Figure 22. TNM Corps training material

Training: Google Map Maker

Google Map Maker was profiled in our 2012 survey and in Paez (2014) as a digitizing application in the same category as OSM and Wikimapia, which suggests that a primary focus of the application is the generation of map features. Its training combines some features also found in the training from Waze and OSM. The interactive training is embedded in the map interface, with videos demonstrating how to use each feature of the editor tool with step-by-step instructions (Figure 23). Google Map Maker also provides a Help Center, which explains the project in more detail, and provides additional information such as videos and tutorials, community resources, and troubleshooting (Figure 24).

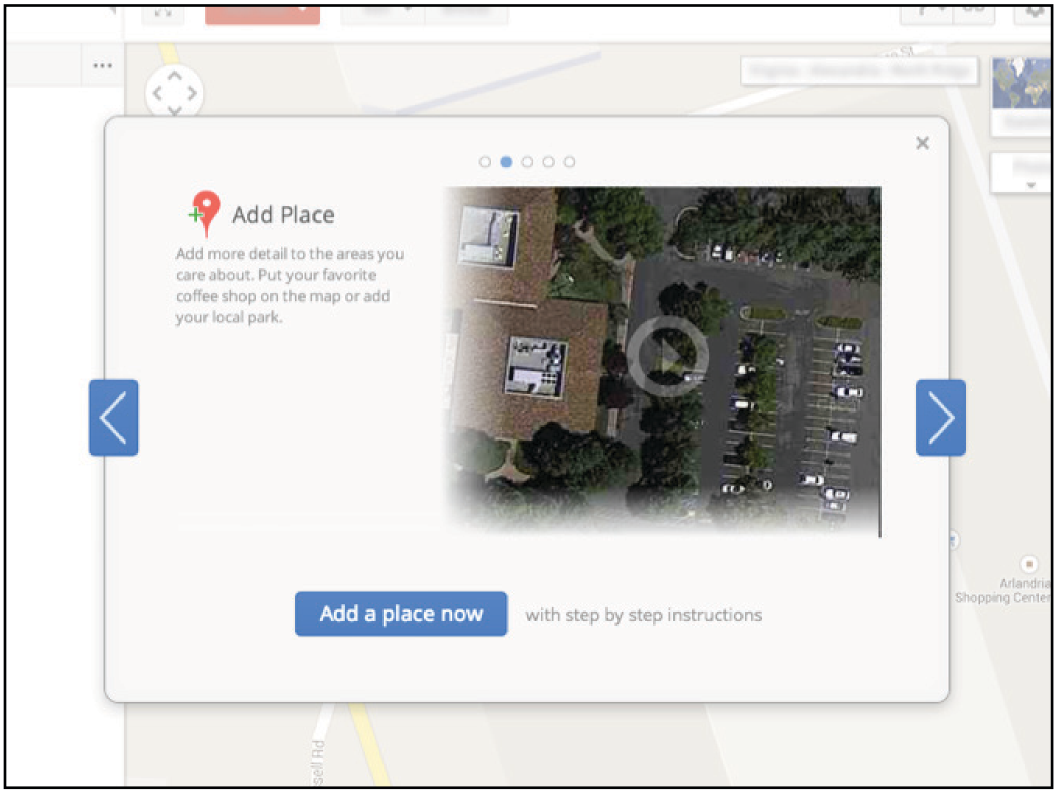


Figure 23. Google Map Maker embedded training material

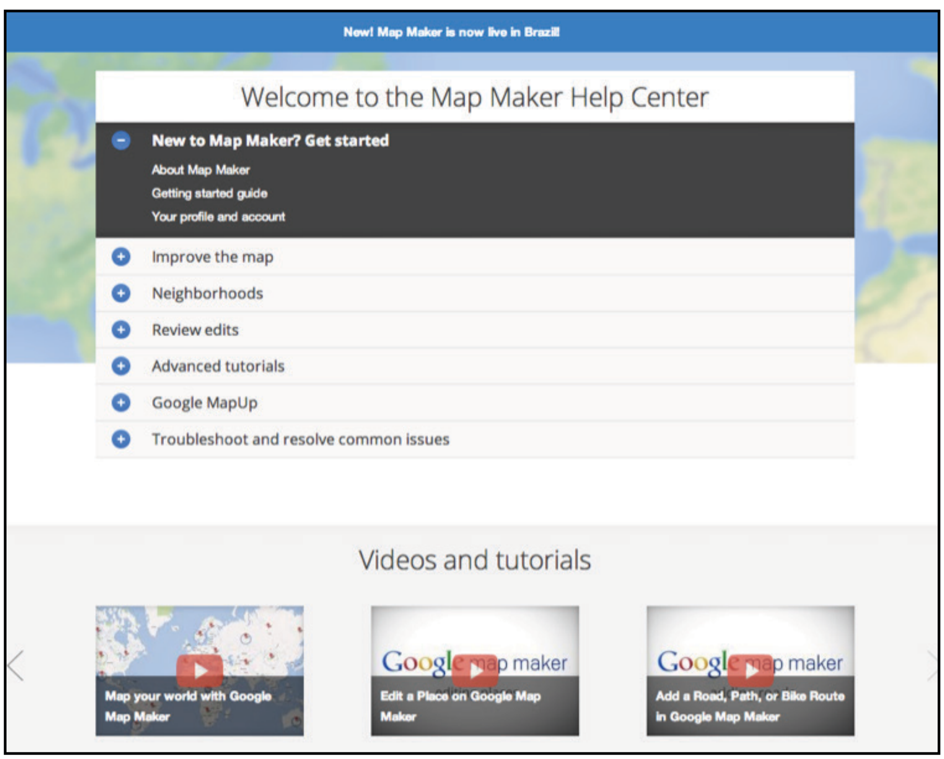


Figure 24. Google Map Maker additional information and training material

### Summary of Training Examples

Each of the four examples from this section is unique in some way, but there are also strong similarities. Based on the success of the applications, these similarities could be considered best practices in training for geocrowdsourcing. First, each training example includes general information about the project and its purpose. Second, each of the training examples provides some interactive, animated, video-based, or graphical explanation of the applications functionality. Projects with a strong commercial motivation (e.g. Waze) tend to have effective, simple, and well-produced training material. On the other end of the spectrum is the USGS' TNM Corps, which has simple and informative training content, but with static graphics in a much more traditional format.

## The GMU Geocrowdsourcing Testbed Training

The ideas from this short survey of training material in four popular geo-crowdsourcing applications have aided and will continue to improve the development of our own training materials. We are not a commercial firm like Google, or a commercial product like Waze, nor are we a traditional and formal government agency. It would not be sensible to hire commercial firms for producing elaborate video content, but we have tried to use the best methods to reach our university audience using the tools and technology available to us and consistent with our goals and funding.

Our training program has a dual goal: to recruit project participants, and to train our participants adequately enough to contribute. This dual goal has been effective to the extent that enough participants have been recruited to generate more than 300 reports (as of September 2014), and most of those reports have provided enough information about transient obstacles to be useful. The training material presented on the following pages is done in two ways: in person through PowerPoint and interactive discussion, and online through Adobe Presenter and recorded video/audio. Of the more than 200 people who have been trained, 149 have participated in in-person training using PowerPoint material and another 52 have participated in online training through Adobe Presenter served through GMU's Blackboard System. Twenty-eight individuals have contributed obstacle reports to our system.

The training material is designed and structured to take no more than 20 minutes, consistent with design practices recommended by educators in

GMU's Division of Instructional Technology, and includes many of the same general categories of information identified in the previously profiled training material:

- A general project overview and statement of purpose,
- A graphical explanation of application functionality, and
- A short assessment

Figure 25 and Figure 26 show the PowerPoint slides created for the general project overview and purpose statement. They include concise descriptions of the problem and purpose of the research (Figure 25) and a brief description of crowdsourcing (Figure 26).

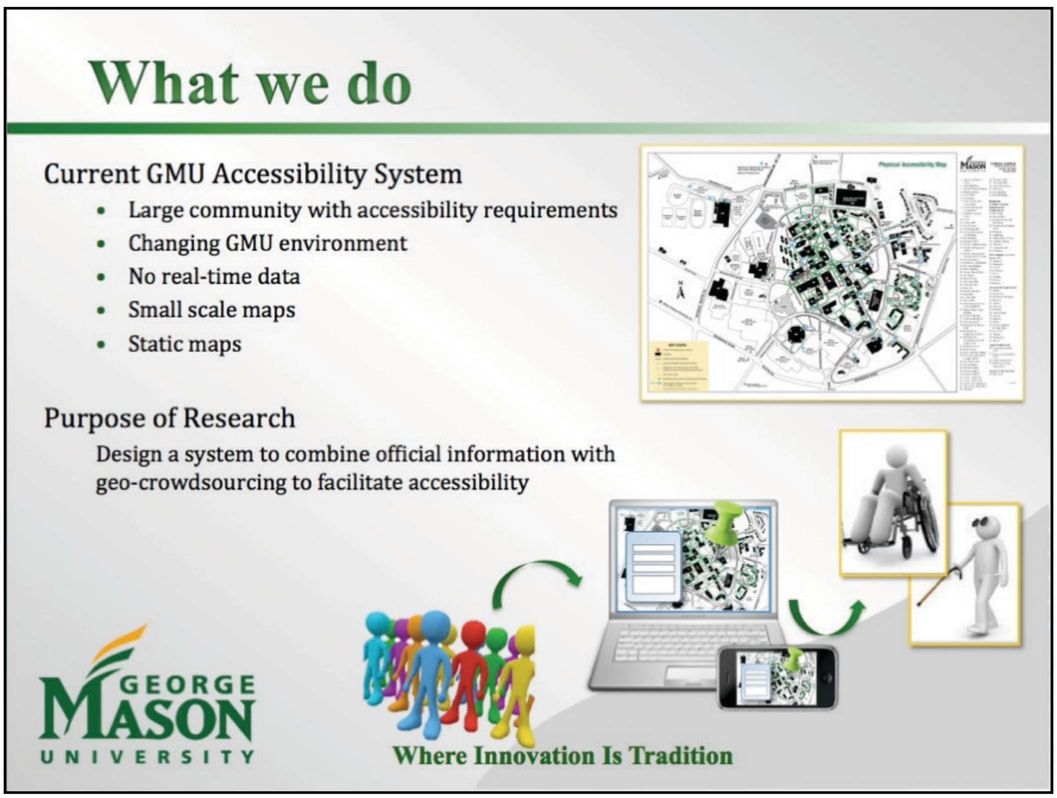


Figure 25. Training material - Introduction to the research problem and purpose

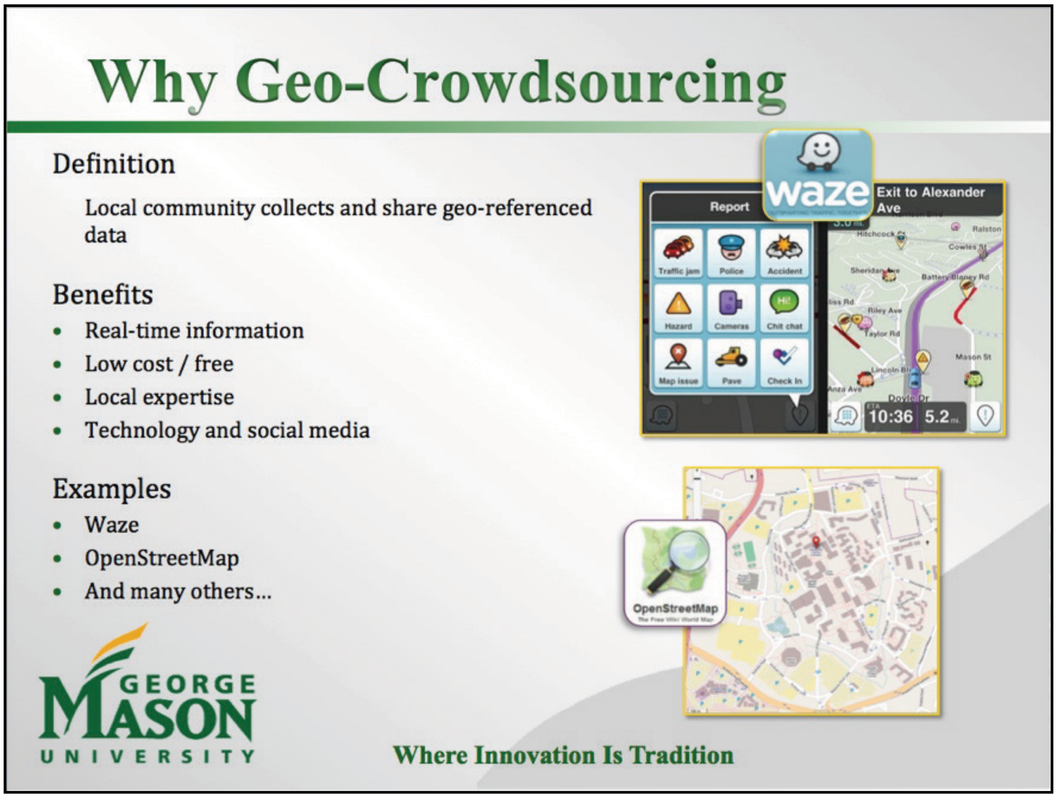


Figure 26. Training material - Introduction to research framework

Next, a functional diagram of the reporting system procedure, shown in Figure 27, introduces the process of reporting obstacles in a set of ordered steps. The diagram portrays the reporting process as simple and fast.

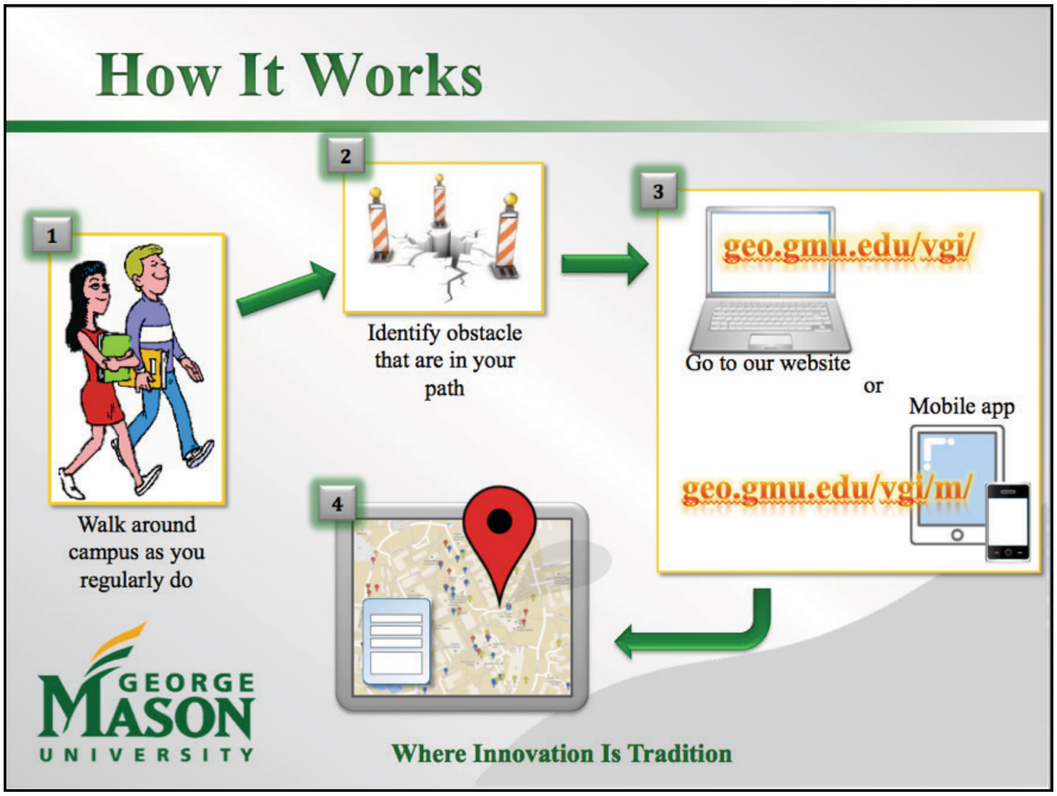


Figure 27. Training material - Obstacle reporting process

After the reporting process is presented conceptually (Figure 27) each of the steps necessary to complete the reporting process is explained in detail on a series of eight slides similar to Figure 28, where the reporting interface is shown with limited-text labels highlighting data entry or interaction points. In this case, the participant is shown where to enter a user-ID and the date/time of the report.

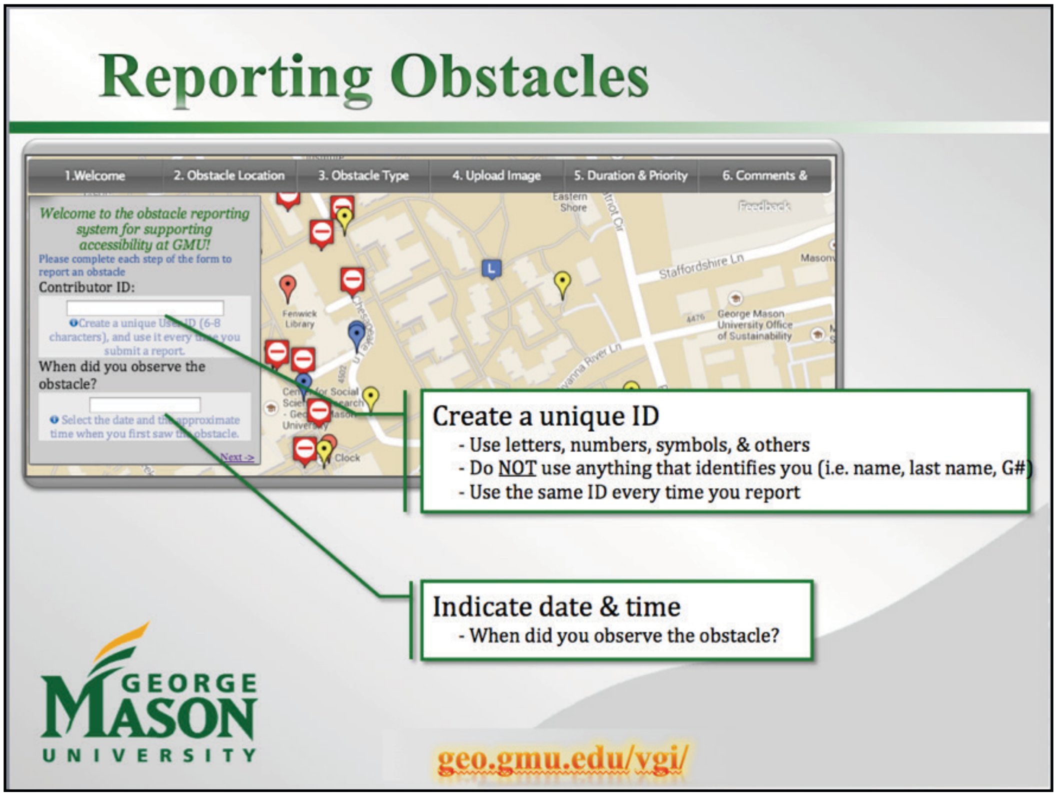


Figure 28. Training material – Obstacle-reporting online form

The final section of the training provides more detail on the obstacle reporting process. This section provides representative examples of each major obstacle type in our system. These representative examples take the form of images selected through the consensus of project staff to be most representative of each object type (Figure 29). Participants learn to characterize obstacles by viewing these representative images and the associated type of obstacle, the duration estimate and the urgency or priority estimate. Figure 29 shows a slide of one of the five examples given during the training. The image shows a cracked sidewalk, representing the obstacle category of “poor surface condition,” and which might pose a significant inconvenience to a person with mobility impairment, meaning the hazard is of medium urgency. The duration category refers to the amount of time that the hazard will be in place. A hazard consisting of a cracked sidewalk, which will most likely require more than seven days to be fixed, would be considered of long duration.

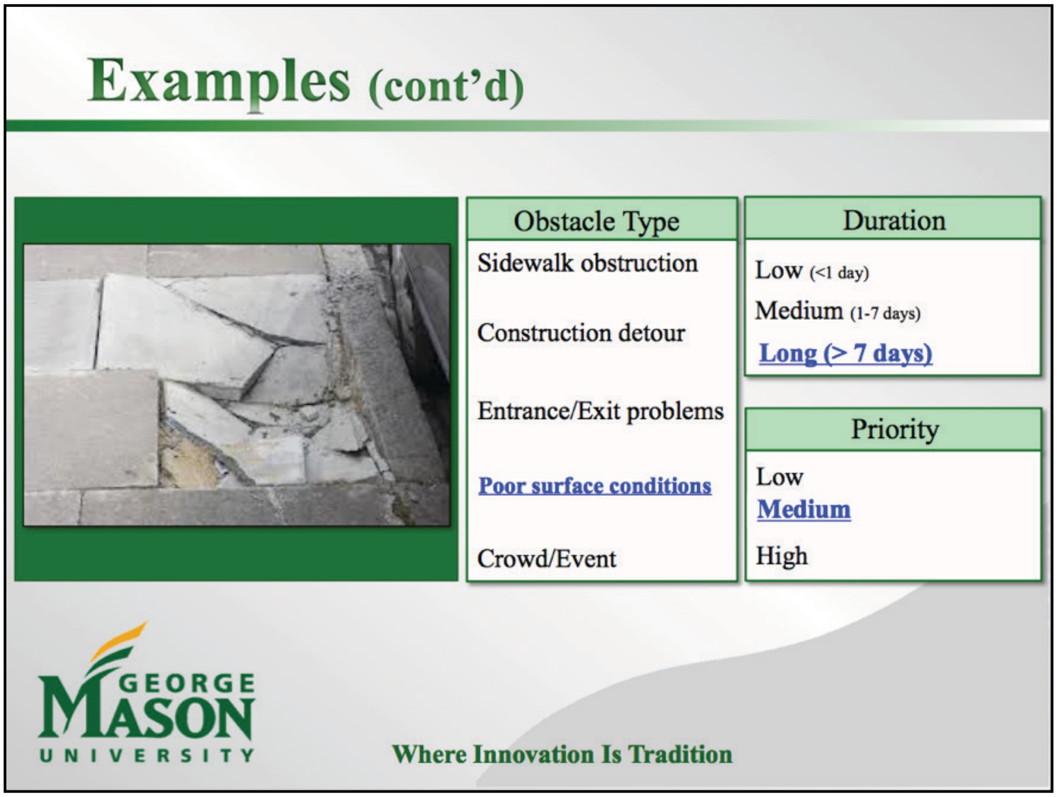


Figure 29. Training material - Examples and assessment of obstacles

After explaining how to assess each type of obstacle, a categorization exercise is provided to participants. The categorization exercise has (in the past) been used to evaluate the quality of the training, and how well the participants understand both the training and the obstacle attributes they had to report. The participants are told that the exercise is not a test and there was no right or wrong answer. The categorization exercise consists of 15 pictures of obstacles (Figure 30), each displayed for 20 seconds, during which time the participants makes an obstacle type, obstacle duration, and obstacle urgency assessment. The obstacle pictures were taken within GMU Fairfax campus and the surrounding neighborhoods, in order to make the assessment realistic and reflective of the types of obstacles likely to be encountered during future report contributions.


Figure 30. Categorization exercise - Sample of the pictures of obstacles

Participants are provided an answer sheet to record their obstacle assessments. The categorization answer sheet is designed using simple-choice answers in the categories of obstacle type, duration, and urgency, which were the same categories explained in the previous section of the training.

## Conclusions and Summary

The purpose of our training program is to recruit contributors and participants, as well as provide knowledge of the project and applications that will lead to higher quality contributions. Efforts to improve training may pay off directly with higher quality data. Future versions of the training material for the GMU Geocrowdsourcing Testbed will be built using this material as a framework, and where possible, will be incorporated into the tool interface, so that small elements of learning or training can be done while using the tools.

Baldwin and Ford (1988)[95] note that many training systems have a significant transfer problem, where trainees have a difficult time applying knowledge and skills learned during training to subsequent tasks and jobs. They estimate that in some industrial training settings, no more than 10% of the training expenditures result in the transfer of skills to a related job. One conclusion drawn from Baldwin's and Ford's research is that periodic review of training materials, referred to as "booster sessions," as well as continued periodic reinforcement from a trainer, have a positive effect in a trainee's retaining the knowledge and skills.

John Carroll's 1990 exploration of minimalist interface design and training in computer tasks, "The Nurnberg Funnel: Designing minimalist instruction for practical computer skill"[96], and Farkas and Williams (1990) review of Carroll's work, suggest a few ideas.[97] Carroll's critique of systematic training, where tasks are broken down into sub-tasks and presented sequentially in tutorials prior to working on a task, ignores the computer user's interest in quickly immersing himself/herself in activity where they can exercise their problem solving abilities. Carroll suggests that training materials should be built from short, tasks-specific modules rather than lengthy user-manual narratives. While Farkas and Williams support many of Carroll's assertions in his promotion of minimalist training approaches and experiential learning, they advocate flexible computer training methods where diverse learning styles can be accommodated.

The "learning while doing" aspect of training, which echoes some of Carroll's minimalist ideas, may be effective in allowing users to quickly transfer knowledge gained from training immediately to the actual task of contributing reports. This approach is similar to the general way that Waze, Google, and OSM approach training. For users with an intuitive understanding of the process, the training (broken into smaller embedded modules) could be skipped completely, while for other users requiring more detail and instruction, the embedded training modules could be completed at their own speed and would provide the periodic review (or "booster sessions") discussed by Baldwin and Ford. The current training material for the GMU Geocrowdsourcing Testbed has a linear, fixed-length format due

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95 Timothy T. Baldwin and J. Kevin Ford, "Transfer of Training: A Review and Directions for Future Research," *Personnel Psychology* 41, no. 1 (1988): 63–105.

96 John M. Carroll, *The Nurnberg Funnel: Designing Minimalist Instruction for Practical Computer Skill* (MIT Press, 1990).

97 David K. Farkas and Thomas R. Williams, "John Carroll's the Nurnberg Funnel and Minimalist Documentation," *IEEE Transactions on Professional Communication* 33, no. 4 (1990): 182–87.

to its reliance on PowerPoint. Allowing potential contributors to engage in the training when they need it, and ignore it otherwise, will be a future direction for our work.

The next chapter of this report looks at two new application areas for our testbed: routing and visualization. These new application areas extend the GMU Geocrowdsourcing Testbed's capabilities into new areas of interest to our sponsors, partners, and research staff.

# 4 Extension of the GMU Geocrowdsourcing Testbed: Routing

After losing his eyesight as an adult, Dr. Reginald Golledge and colleagues developed the UCSB Personal Guidance System (Figure 3) to help Dr. Golledge navigate across the college campus where he worked (Loomis et al. 2005).[98] The 2003 version of the system shown in Figure 3 consists of a GPS receiver, and head-mounted fluxgate compass, a geographic information system on a laptop computer, and a handheld tactile pointer interface. Along with tactile maps and graphics, Dr. Golledge could learn the spatial layout and configuration of sidewalks, buildings, entrances, exits, and landmarks and successfully route himself across campus. A body of subsidiary research was done by Dr. Golledge and colleagues to discover the best methods for routing blind, visually-impaired, and mobility-impaired individuals. As noted in the introductory chapter of this report, the major drawback in the UCSB Personal Guidance System is its inability to incorporate transient obstacles that hinder navigation. The purpose of the GMU Geocrowdsourcing Testbed is to provide this obstacle information through crowdsourcing.

Nuernberger (2008) developed a system for real-time communication with mobility-impaired individuals to enhance their ability to choose routes and avoid obstacles. Barbeau (2010) developed a notification system for communicating routing information to disabled individuals riding public transit. Kasemsuppakorn and Karimi (2009) implement a wheelchair routing method using the multiple parameters such as slope, sidewalk conditions, traffic loads, and other personal preferences. Their method uses impedance scores for individual sidewalk segments to determine an optimal route.[99] In a later paper (2013) they emphasize the importance of developing accessible routing applications with a true pedestrian network rather than a roadway, and offer advice on analytical and participatory mapping approaches to accessibility.[100] Beale et al. (2006) implement

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[98] Loomis et al., “Personal Guidance System for People with Visual Impairment: A Comparison of Spatial Displays for Route Guidance.”

[99] Piyawan Kasemsuppakorn and Hassan A. Karimi, “Personalised Routing for Wheelchair Navigation,” *Journal of Location Based Services* 3, no. 1 (2009): 24–54.

[100] Hassan A. Karimi and Piyawan Kasemsuppakorn, “Pedestrian Network Map Generation Approaches and Recommendation,” *International Journal of Geographical Information Science* 27, no. 5 (2013): 947–62.

a network model in GIS for accessibility mapping that takes into account slope, surface type, and the presence of curb cuts.[101]

Several good examples of accessible routing applications can be seen in the pgRouting Gallery[102], where examples of open source routing are linked. Two notable examples from that page are the Portuguese Accessible Paths in Pinhel portal (Figure 31)[103], and the campus map of the Federal Polytechnical School of Lausanne (EPFL, Figure 32)[104]. The Paths in Pinhel mapping portal allows for the selection and display of paths suitable for wheelchair users, and alternatively, paths suitable for seniors and those with minor mobility impairments, taking into account both slope and the pathway material. The EPFL campus map allows for accessible routing between and through campus buildings, avoiding stairways and steep paths. Both applications (Figure 31 and Figure 32) use obstacle avoidance and criteria for determining what constitutes an accessible route; in the case of Accessible Paths in Pinhel, these criteria are accompanied by explanatory text and pictures. Both applications may fail to find an accessible route, particularly the EPFL campus map, which employs a more sophisticated routing approach using interior passageways. A notable strength of the Accessible Paths in Pinhel portal is detailed step-by-step directions with pathway widths and obstacle notifications. A notable strength of the EPFL campus map is its extension of the routing network to interior spaces and the graphical floor indicator (Figure 32) showing end-users where they will be required to change floors.

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[101] Linda Beale et al., "Mapping for Wheelchair Users: Route Navigation in Urban Spaces," *The Cartographic Journal* 43, no. 1 (2006): 68–81.

[102] http://pgrouting.org/gallery.html

[103] See http://percursos.pinhel.proasolutions.pt/ [accessed September 24, 2014]

[104] http://plan.epfl.ch/ [accessed September 24, 2014]


Figure 31. Wheelchair accessible route generated by Accessible Paths in Pinhel Mapping Portal

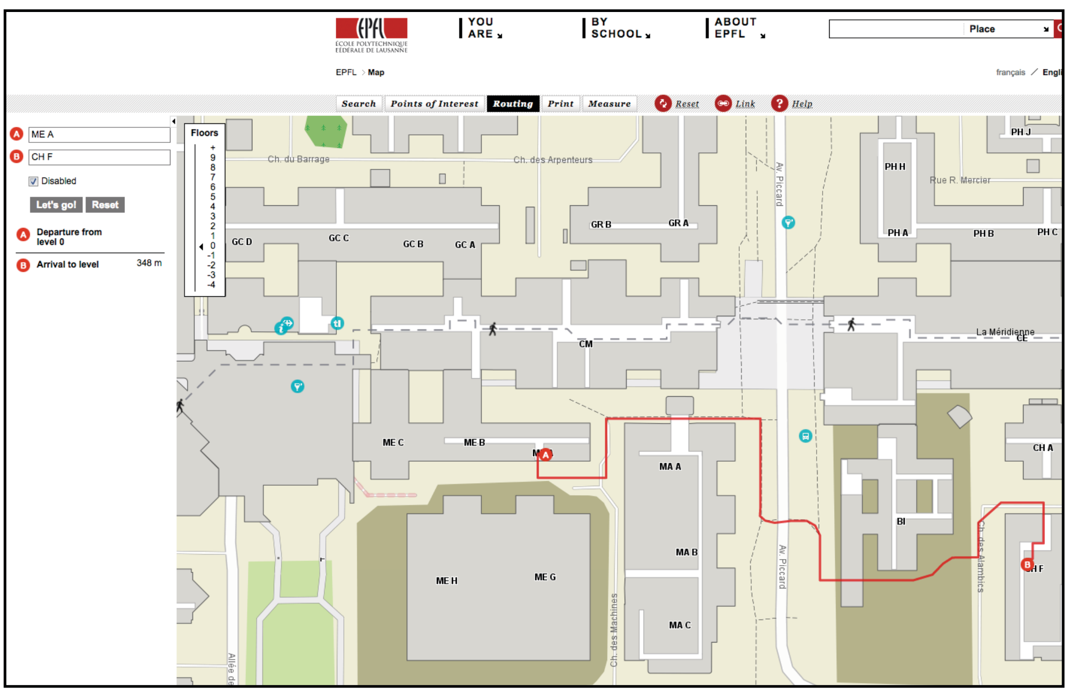


Figure 32. Federal Polytechnical School of Lausanne campus map with accessible routing

The GMU Geocrowdsourcing Testbed adds to this existing body of research in this area by demonstrating how transient obstacle information can be collected through crowdsourcing, and displayed on a map to provide information to individuals. The next logical step in this process is the development of a routing capability in the GMU Geocrowdsourcing Testbed, to help end-users avoid the transient obstacles collected through the system. Our work in this effort is based on the best ideas from the accessible mapping resources reviewed here and the research findings of authors such as Beale et al., Kasemsuppakorn, and Karimi. The following sections of this chapter address the development of routing capabilities and some of our preliminary findings.

## Routing

### Routing Data

No entity on campus or in the region has access to or has created a high quality map for pedestrian infrastructure. OpenStreetMap, predictably, is the closest, with public domain datasets for walking paths on campus, but the connections of these paths with neighboring jurisdictions is missing. Typical routing applications, even those asserted to be for pedestrians, utilize street networks (Figure 33).

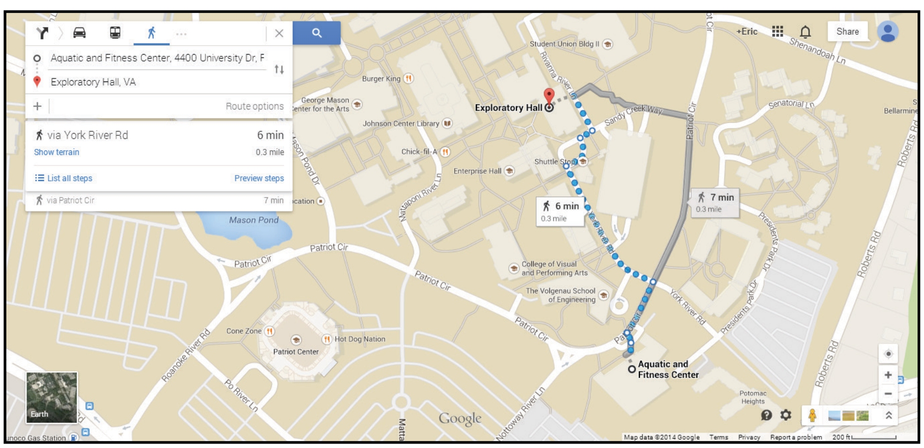


Figure 33. Google Maps "pedestrian" routing uses GMU campus roadways

Project researcher Eric W. Ong studied the pedestrian routing capabilities within the mapping products of Google, Microsoft, and Yahoo, and concluded that none of them utilize pedestrian networks over the entire study area. To fill the clear need, project staff created a comprehensive pedestrian network for the region, and created datasets of the related pedestrian features, such as sidewalk centerlines, crosswalks, stairways, steep paths, bridges, informal pathways, and curb cuts (Figure 34). Editing and refinement of this network is ongoing and updates are made on a weekly basis, with a focus on topological consistency and the extension of the routing network to interior spaces of large buildings that are commonly used during navigation across campus. The research staff of this project, GMU Parking and Transportation Services, and GMU Facilities staff will jointly maintain the network and associated data. The routing data is part of a larger network analysis and map service deployed on ArcGIS Server v.10.1, Windows Server, and the Esri API for JavaScript with HTML, CSS, and JavaScript customization. This service is under development and changes frequently. It can be found at: http://geo.gmu.edu/route.

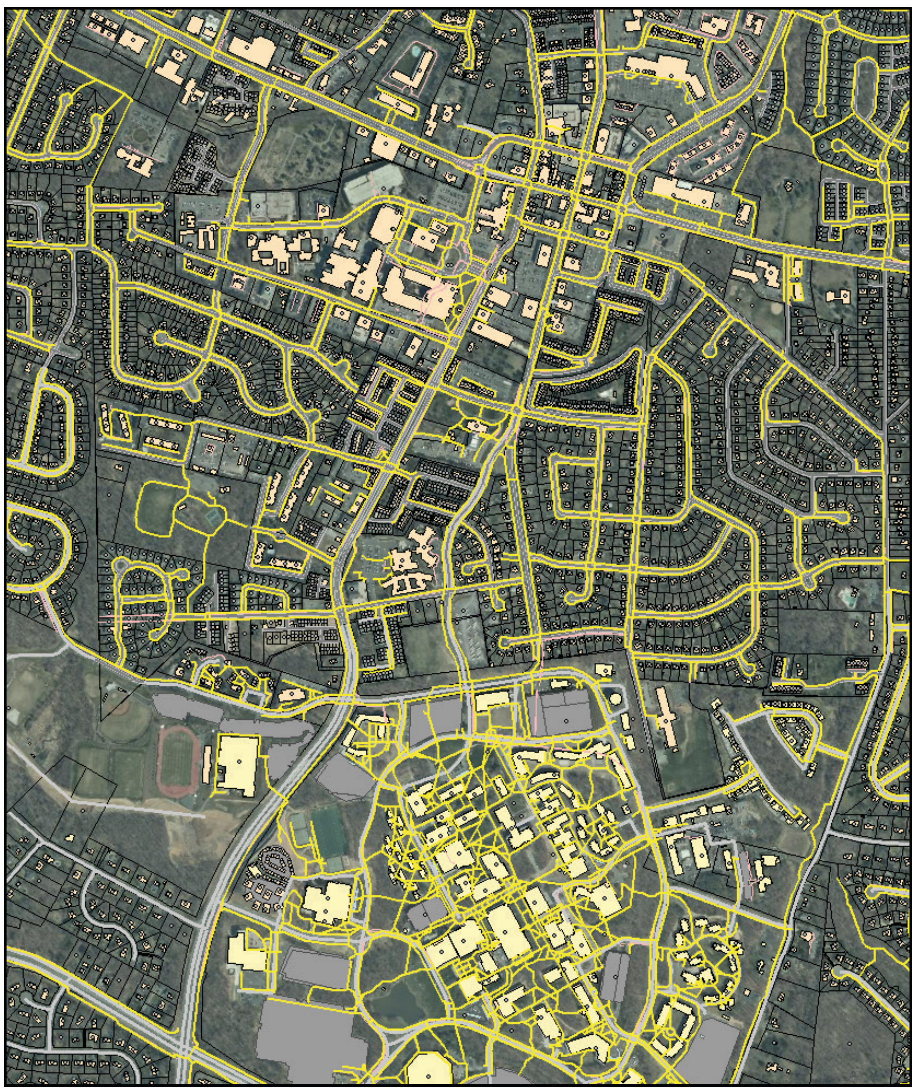

Figure 34. Pedestrian Network (yellow) superimposed on image of region

Exploring Routing Dynamics with the GMU Geocrowdsourcing Testbed

Pedestrian behavior on campus is poorly understood, especially the behavior of students, faculty, staff, and visitors that are disabled. Only one GMU staff member (interviewed extensively for this report) is trained and certified as a disabled orientation and mobility specialist. Having dealt with similar problems in a similar setting nearly twenty years ago, project collaborator James Marston published work with Dr. Richard Church in 2003, where they assert that traditional measures of accessibility are flawed, and do not take into account the vast physical and mobility differences of individuals.[105] They propose a sophisticated system of measuring access as a way of accommodating these differences, as well as accommodating the many structural barriers that affect travel time and effort. A map from their study (Figure 35) shows that the routes used by disabled travelers vary greatly, and have very different distance and difficulty characteristics.

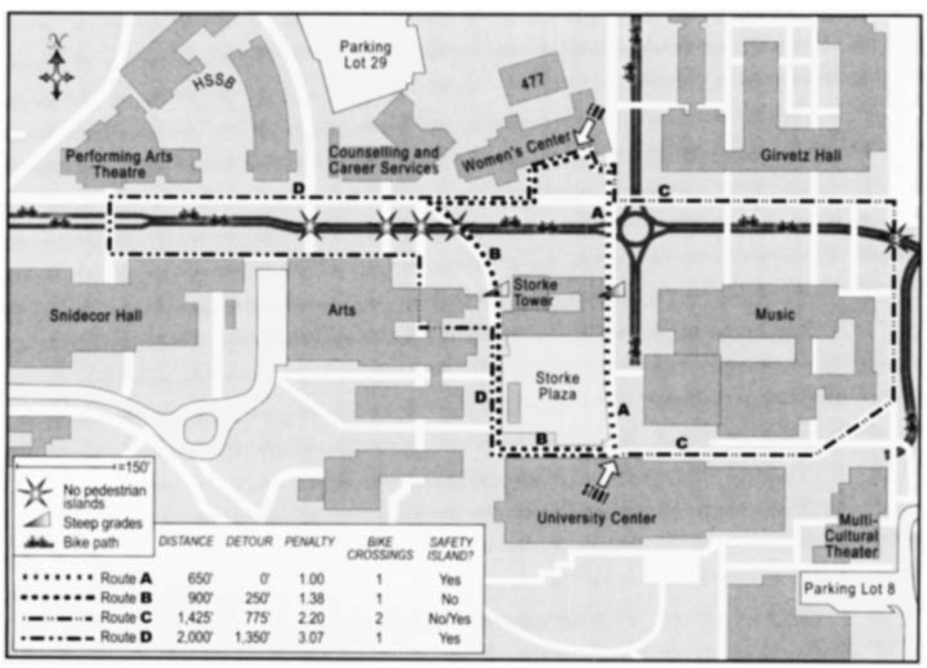


Figure 35. Routing and Accessibility Study, Church and Marston (2003)

[105] Richard L. Church and James R. Marston, "Measuring Accessibility for People with a Disability," *Geographical Analysis* 35, no. 1 (2003): 83–96.

To understand how disabled pedestrians travel in our area, we developed the routing application discussed above, and developed routing scenarios with several disabled travelers. Figure 36 shows the first routing scenario discussed with one of our system end-users who uses a wheelchair to navigate on the GMU campus and in downtown Fairfax City near his workplace. The scenario involved routing from the west side of Fairfax City Hall to the Starbucks on the north side of the GMU campus. The scenario utilizes our routing application, with the origin and destination shown with black crosses and the normal route shown in red (dashed line). The imposition of an obstacle from our system (shown with a red cross) significantly lengthens and extends the path required to have an accessible route, which is shown with a solid green line. The end-user verified that the routing scenario shown in green is realistic, but noted that it does not consider the slope of the route, which is more significant with the imposed detour.

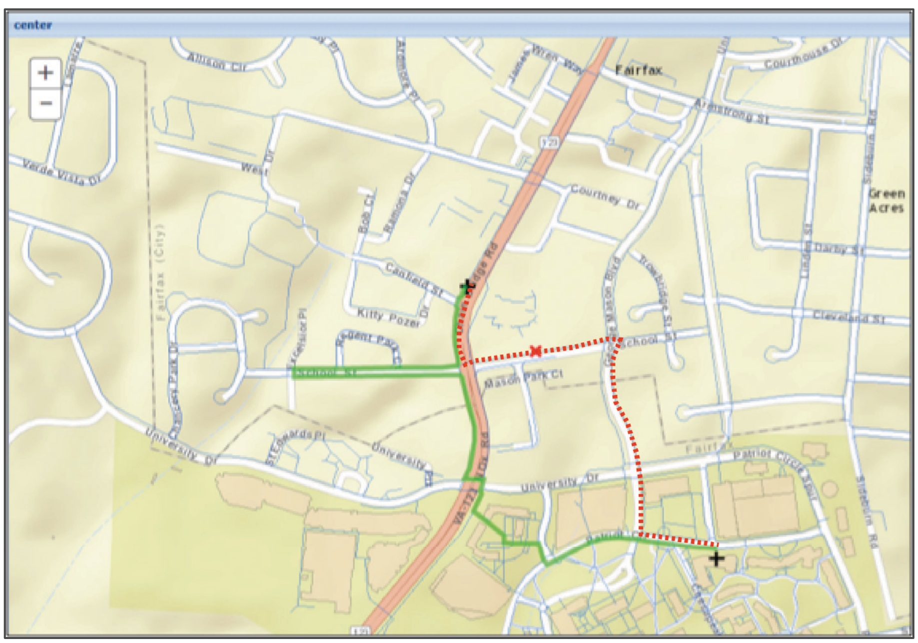


Figure 36. The effect of imposing an obstacle on a route.

Figure 37 shows a second routing scenario with the same end-user, where we discussed his likely direction of travel from an address in downtown Fairfax City close to his workplace, to the Safeway store in Courthouse Plaza. As can be seen in Figure 37, our routing application produced an accessible routing on a pedestrian corridor through the parking lot in front of the store (Figure 37, in green). During discussion with the end-user, we realized that a critical sidewalk extension within the parking lot (Figure 38) was missing from our underlying network routing dataset. His preferred route under this scenario would have used this sidewalk extension and an informal path through the parking lot, shown in red (Figure 37). This informal path is slightly shorter, but was not chosen by our routing application due to the missing segment, highlighting the importance of informal and unmapped routes through large navigable areas.

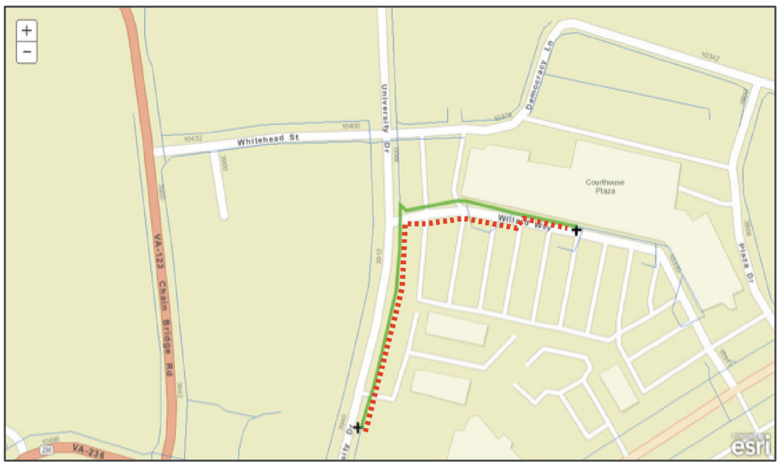


Figure 37. The effect of a missing sidewalk section and ad-hoc routing


Figure 38. The missing sidewalk section (pictured) in Courthouse Plaza shopping center, north of GMU campus.

The end-user interviewed during this research activity requested that we develop a method (similar to those within Google Maps, Waze, and OpenStreetMap), for adding new pedestrian network sections. To highlight this issue, the end-user pointed out a temporary third crosswalk not more than 100 yards from our interview location in downtown Fairfax City, associated with the closure of sidewalks and the reconstruction of Kitty Pozer Park (Figure 39). Being able to quickly accept reports of this type and being able to modify the underlying pedestrian network, as would be needed in this case, is an important capability that we will add to our system in the future.


Figure 39. New crosswalk, created during construction of Kitty Pozer Park.

Interviews with two other end-users produced similar results. The routing scenario shown in Figure 40 involved a trip from the vicinity of a workplace to the GMU Commerce Building. While the shortest-cost route is relatively simple and easy to visualize (red dashed line), the accessible route is shown in solid green. This route is specific to a side of street (in order to avoid obstacles located on an opposite side), and directs the end-user across a crosswalk near the GMU Commerce Building. This unusual route was discussed with the end-users and determined to be valid but not a preferred route due to the difficulty of crossing the street using the crosswalk on University Drive near the GMU Commerce Building.

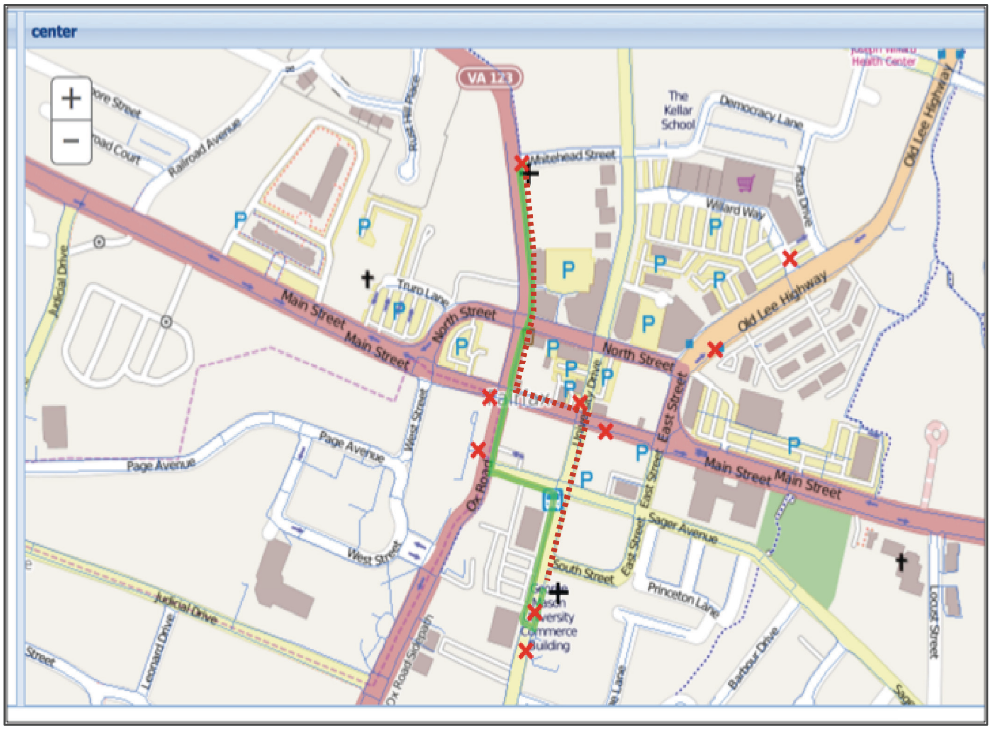


Figure 40: User routing scenario - obstacle avoidance and side of street selection

While the routing scenarios and solutions obtained from our system were deemed to be reasonable and valid according to all end-users interviewed, the individuals raised a number of very useful issues that we will discuss here and consider in future system development.

One significant issue is that end-user route choice and route preference are highly variable and highly individual. This issue is well known among orientation and mobility specialists and the disabled community, but is not more broadly understood. Church and Marston (2003)[106] verify this fact in their study, as does the work of Jacobson (1998)[107], Golledge (1999)[108], Williams et al. (2013)[109], Avila (2014)[110], and Golledge et al.

106 Ibid.

107 R. Dan Jacobson, "Cognitive Mapping without Sight: Four Preliminary Studies of Spatial Learning," *Journal of Environmental Psychology* 18, no. 3 (1998): 289–305.

108 Reginald G. Golledge, *Wayfinding Behavior: Cognitive Mapping and Other Spatial Processes* (JHU Press, 1999).

(2000)[111], who all note the heterogeneity in preferences associated with route selection and wayfinding behavior. This issue is highlighted prominently by Figure 41, which shows the preferred route of our first end-user subject, who notes the many clear reasons why the much longer route shown in Figure 41 is his preferred route to travel between his dormitory and the Johnson Center on the George Mason Campus. An interesting aspect of the route shown in Figure 41 and in other scenarios reviewed with this subject using our testbed routing application, was that the direction of his travel made a difference in the route he selected, due to the curvature and slope of some paths, which made them easier to traverse in a specific direction. Some of the preferences stated by this end-user support the findings in Church and Marston (2003), Kasemsuppakorn and Karimi (2009, 2013) and Beale et al. (2006).

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[109] Michele A. Williams, Amy Hurst, and Shaun K. Kane, "'Pray before You Step out': Describing Personal and Situational Blind Navigation Behaviors," in *Proceedings of the 15th International ACM SIGACCESS Conference on Computers and Accessibility* (Bellevue, Washington: ACM, 2013), 1–8.

[110] Kimberly Avila, "The Experiences of Pedestrians with Visual Impairments in a Metropolitan Setting: An Ethnographic Inquiry," in *Proceedings, Biannual International Conference of the Association for Education and Rehabilitation for the Blind and Visually Impaired*, San Antonio, TX, 07-14).

[111] Reginald G. Golledge et al., "Cognitive Maps, Spatial Abilities, and Human Wayfinding," *Geographical Review of Japan, Series B* 73, no. 2 (2000): 93–104.

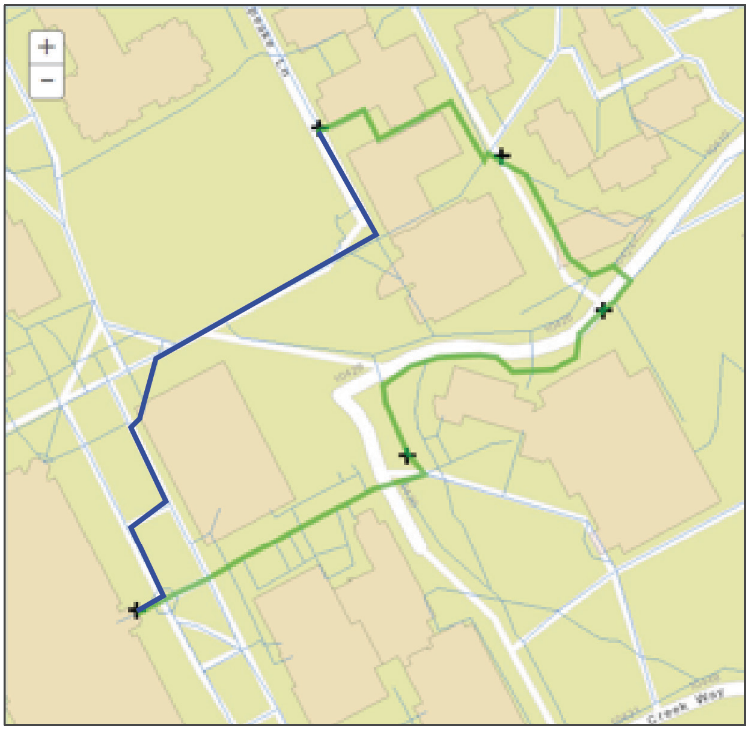


Figure 41. Preferred routes (green) are often longer and more complex than a shortest route (blue)

Pingel (2010a, 2010b) notes that asymmetry in route choice is common, and the slope and direction of travel and make significant changes to route selection.[112,113] Route choice appears to be highly variable and personal and would be difficult to capture in our current system, though some common suggestions, such as the inclusion of elevation and slope, would be important additions during the next phase of our work.

## Conclusions and Summary

The routing work profiled in this chapter represents a strategic extension to our GMU Geocrowdsourcing Testbed, and is of high interest to local campus and municipal authorities, who are struggling to accommodate the growth of the University and the strain this growth puts on the local transportation infrastructure.

112 Thomas J. Pingel, "Modeling Slope as a Contributor to Route Selection in Mountainous Areas," *Cartography and Geographic Information Science* 37, no. 2 (2010): 137–48.

113 Thomas James Pingel, *Strategic Elements of Route Choice* (University of California, Santa Barbara, 2010).

Interesting examples of accessible routing applications profiled earlier in this chapter highlight the usefulness of incorporating slope into our routing algorithms, as well as pathway material, and routing through the inside of buildings to take advantage of elevators.

The routing system discussed in this chapter is based on a pedestrian network and obstacle data from our system. The purpose of this routing system is to provide obstacle-avoiding route suggestions to disabled individuals. Future work on this extension of our testbed will be shared with GMU Parking and Transportation Services, as well as other interested parties. Routing can be difficult, and has been described by a project consultant as a poor demonstration of the capabilities of our system, due to the many ways that an obstacle-avoiding routing application can fail to work properly. We acknowledge and have witnessed the large variation in routing and wayfinding preferences in individuals that have been interviewed for this project, and expect to continue seeing large variations in routing and wayfinding preferences as we expand our user base. The goal of this testbed extension is not to meet every one of those preferences, but to demonstrate the usefulness of crowdsourced geospatial data and the possible uses of the GMU Geocrowdsourcing Testbed.

# 5 Extension of the GMU Geocrowdsourcing Testbed: Visualization

MacEachren describes visualization in the domain of mapping sciences and geography as a fundamental geographic method associated with all aspects of map use in science, with a specific focus on the exploration of unknown phenomena in a highly interactive, private setting. The visualization cube associated with this perspective (Figure 42)[114] is well known and widely accepted as a way of thinking about how computers, geographic information systems, and the Internet have changed the traditional discipline of cartography. The MacEachren Geovisualization Cube suggests that the visualization environments, such as the one being developed in the GMU Geocrowdsourcing Testbed, are typically used for exploring and revealing unknowns through high human-map interaction, and usually in a private setting. Those characteristics, suggested by the MacEachren Cube, match our intended use and development of the GMU Geocrowdsourcing Testbed's visualization capabilities.

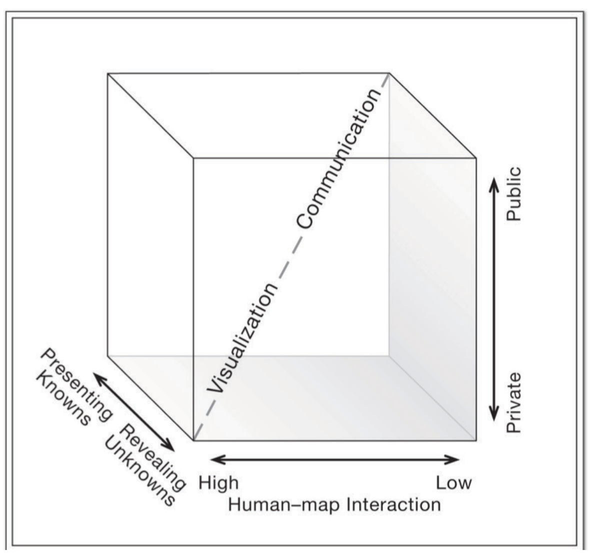


Figure 42. Geovisualization Cube, from MacEachren (1994)

[114] Alan M. MacEachren and David Ruxton Fraser Taylor, *Visualization in Modern Cartography*, vol. 2 (Pergamon Press, 1994), Fig. 1.3, p.6.

## Map Visualizations

Visualization is an important element of our current GMU Geo-crowdsourcing Testbed, and while an interactive map has been at the center of the testbed for its entire history, prior to 2014, we did not have the capability for interactively visualizing the crowdsourced obstacle data and associated quality assessment information. Other than the recent work of researchers in this project, very little previous academic research is available about interactive visualization of pedestrian navigation obstacles. More generally, navigation-centric applications such as Waze, and to a lesser degree, Google Maps, include event information that in some cases indicates an obstacle. Similarly, Travelmidwest.com's map of Chicago (Figure 43) uses an extensive palette of map symbols to show construction zones, incidents, special events, and weather-related closures for vehicular travel around the Chicago metropolitan area. Goldsberry's 2008 paper[115], based on his dissertation work on traffic maps in Los Angeles, contains some useful cartographic ideas about symbolization on traffic maps, which are often focused on arterial congestion and obstacles.

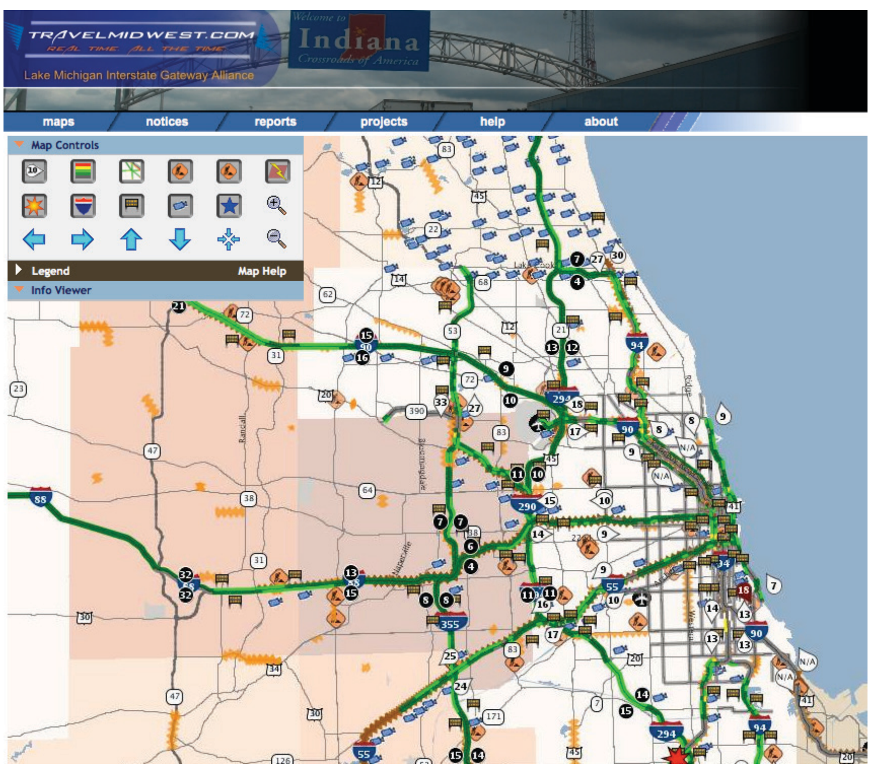


Figure 43. Travelmidwest.com's traffic map of Chicago

[115] Kirk Goldsberry, "GeoVisualization of Automobile Congestion," in *AGILE Workshop on GeoVisualization of Dynamics, Movement and Change, Girona, May*, vol. 5 (Citeseer, 2008).

Our GMU Geocrowdsourcing Testbed map displays are based on Google Map API v.3's base data, and Esri's API for JavaScript, whose base data layer is derived from OpenStreetMap. Application development using a generic mapping API and basemap provides some limitations, and represents a classic problem for cartographers, who have gained the power of the Internet but have inherited mediocre, fixed basemaps that are difficult to customize. As we search for exemplars (specifically web-based mapping and visualization systems) and discover noteworthy cartographic practices, we will adopt them in our project.

### Obstacle Map

Our obstacle-mapping portal can be found at http://geo.gmu.edu/vgi and consists of a standard Google Maps API with point and areal symbols added. Figure 44 shows our current palette of point symbols for representing reports and obstacles. The status of each report and obstacle is stored as an attribute in our database, and a corresponding color is used for display. The choice of simple colors is thought to correspond with readability and quick interpretation. The use of the neutral color gray for closed events allows those reports to be visually separated from the other map content. The larger bright red symbol for obstacles is chosen for emphasis.

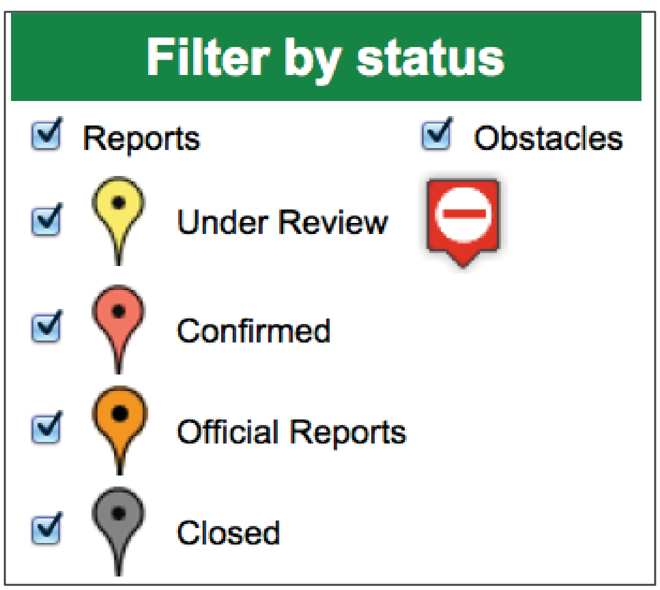


Figure 44: Our palette of symbols for obstacles

One difficult aspect mapping obstacles in a geocrowdsourcing environment is overlap and spacing. Figure 45 shows an area of downtown Fairfax City where the spacing and density of reports and obstacles yields good results. Several closed reports (in gray) and confirmed reports (in red) are visible along with objects (in red). The orange official reports from The City of Fairfax Public Works department, indicating the sidewalk closures associated with the construction of the Kitty Pozer Garden, are visible along with the polygon-based footprint for the authoritative or official report.

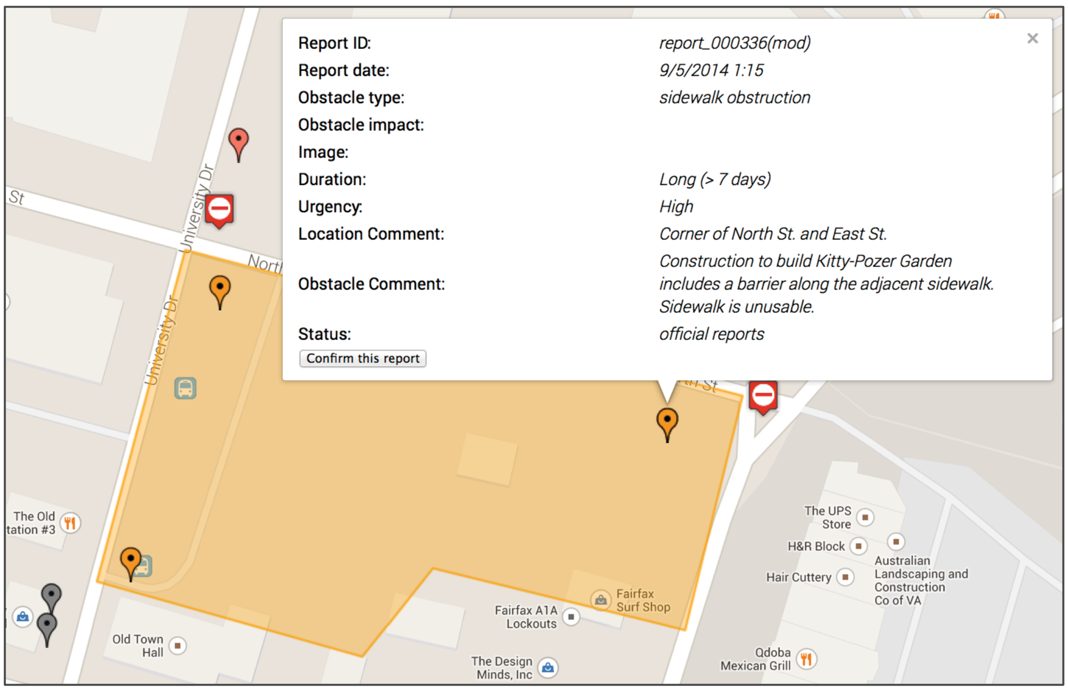


Figure 45. Obstacle map in the downtown area of the City of Fairfax

Figure 46, in contrast, demonstrates the significant problem with spacing and density for areas with many reports, such as this walkway in-between Robinson A and the Fenwick Library on the GMU campus, which is under construction. While the orange official report can be seen clearly, many of the other confirmed reports and obstacles overlap, and any information pop-ups (such as in Figure 45) make this cartographic problem worse. Future work in visualization for the GMU Geocrowdsourcing Testbed will include solutions for automating the spacing and density of contributed reports in order to improve obstacle maps and visual display. Dias (2013)[116] and Dias et al. (2014)[117] address some of these issues in their geovisualization work and mashup tools, which uses grid-based clustering to simplify the visual display of dense point data. Approaches adapted from Dias et al. and other best practices will be used to improve the visual display.

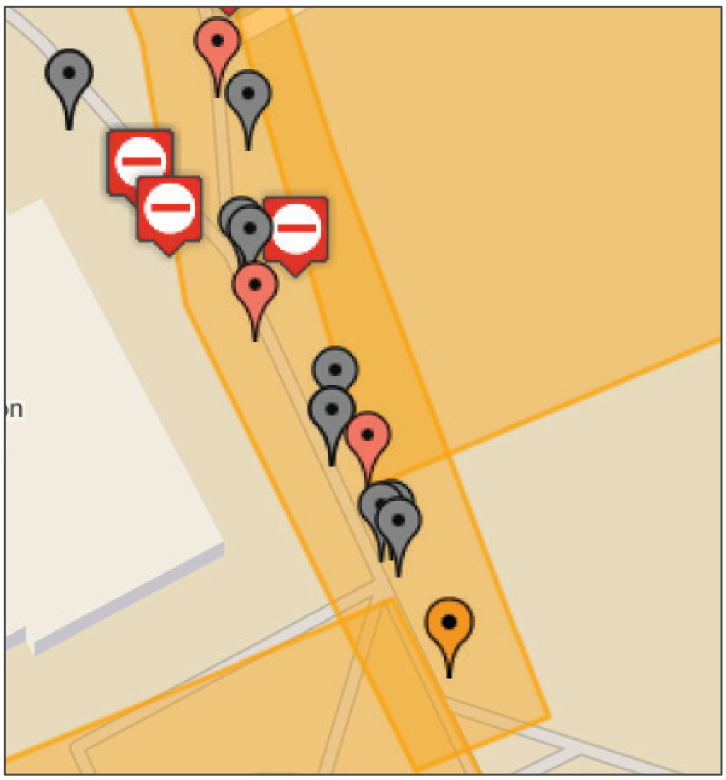

Figure 46. Dense collection of reports and obstacles near the Fenwick Library

### Route Map

The route mapping portal under development for this project (Figure 47) uses Esri's API for JavaScript and their standard OpenStreetMap base layer, which has a better representation of campus buildings and features than any of the basemaps available through Esri's API. This base data layer uses standard OSM symbolization and has generic mapping controls directly from the Esri API. Because we have significant local geospatial data and the Esri API can facilitate the creation of a custom base layer, we will

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116 Shawn Bosco Dias, "Geovisualisation Mashup Tool to Provide Better Situation Awareness for Earthquakes" (Master's of Science Thesis, George Mason University, 2013).

117 Shawn B. Dias et al., "Mashing Up Geographic Information for Responding to Emergencies - An Example with Earthquake," *Journal of Geographic Information System*, 2014.

change the cartographic aspects of this standard routing map in the near future. This interface allows us to select origins and destinations with a mouse click or screen tap, create custom routes using stops and barriers, and display the current obstacle data from our system as red crosses, which can be avoided. Future work on this routing map will include the creation of a base data layer from our own collections of data, as well as better point symbolization for origins, destinations, and obstacles.

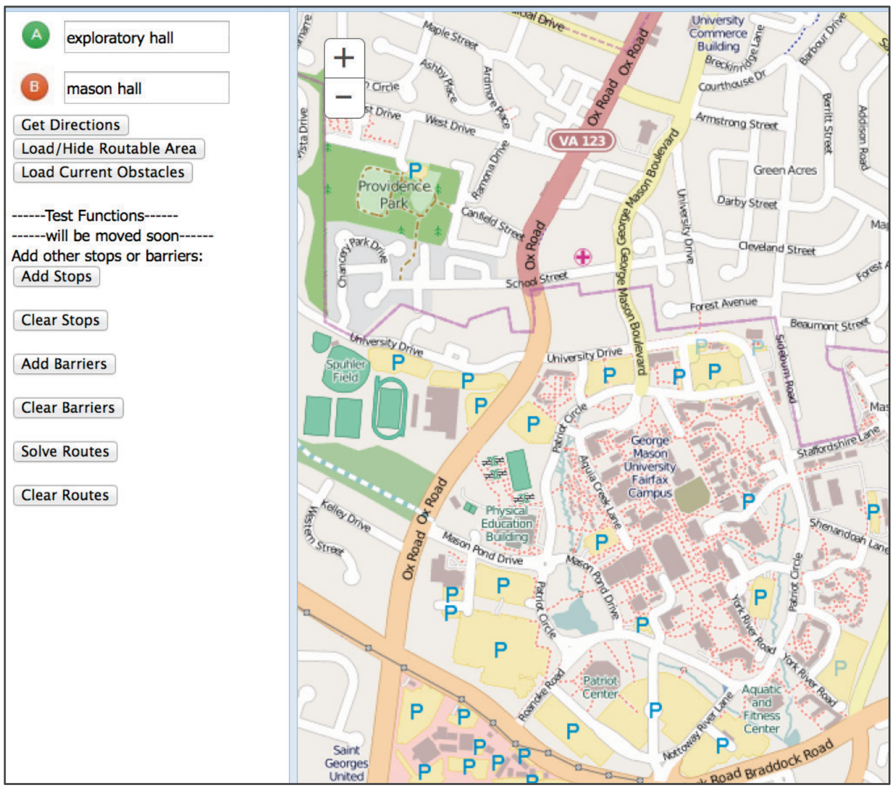


Figure 47. Routing map, using Esri's API for JavaScript and OpenStreetMap base data

## Bicycle Map

These routing tools follow the efforts of project researcher Jessica Fayne, to build a bike map and related routing applications for GMU Parking and Transportation Services. Fayne’s popular bike map (Figure 48), printed on microfiber cloth, is in high demand. Jessica’s work on this project was advised by project personnel, and funded by Fairfax County Department of Transportation and the GMU Parking and Transportation Services and will continue during the upcoming year, funded partially by this research effort. This joint work reflects the strong interest in GMU Parking and Transportation Services to work with our research group to address nonvehicular transportation options and to address the mapping infrastructure to support these options.

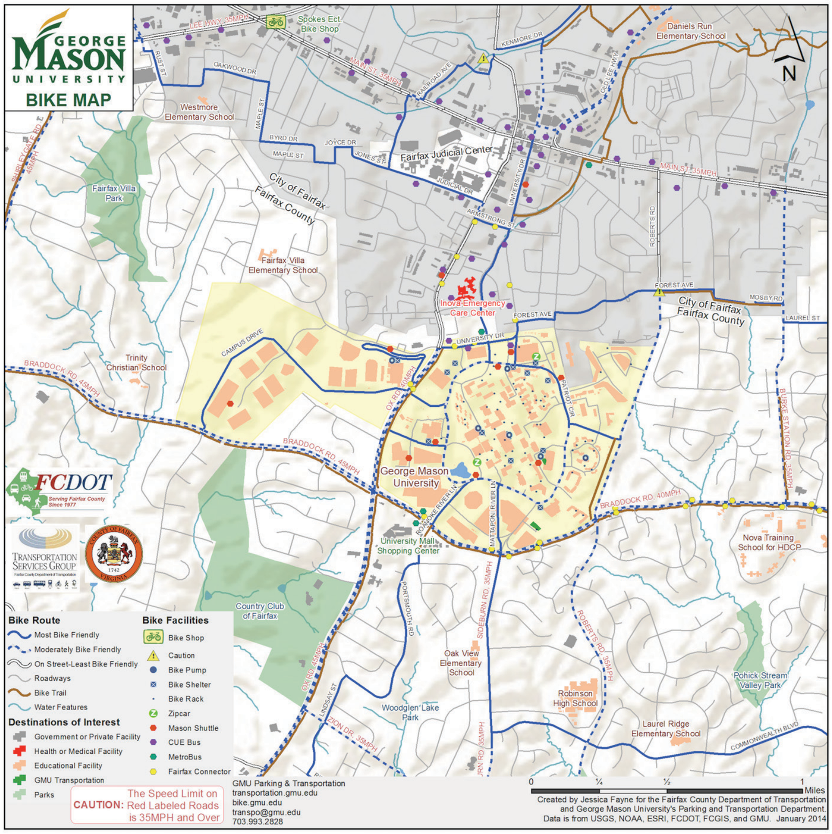


Figure 48. Jessica Fayne's microfiber bike map design

Fayne extended the bike mapping effort (Figure 48) with the creation of a GMU Parking and Transportation Services Mapping Portal (Figure 49), which supports information about bike sharing, car sharing, and infrastructure used by both. Our routing service will add to these resources, and will be developed jointly through Fayne with GMU Parking and Transportation Services.

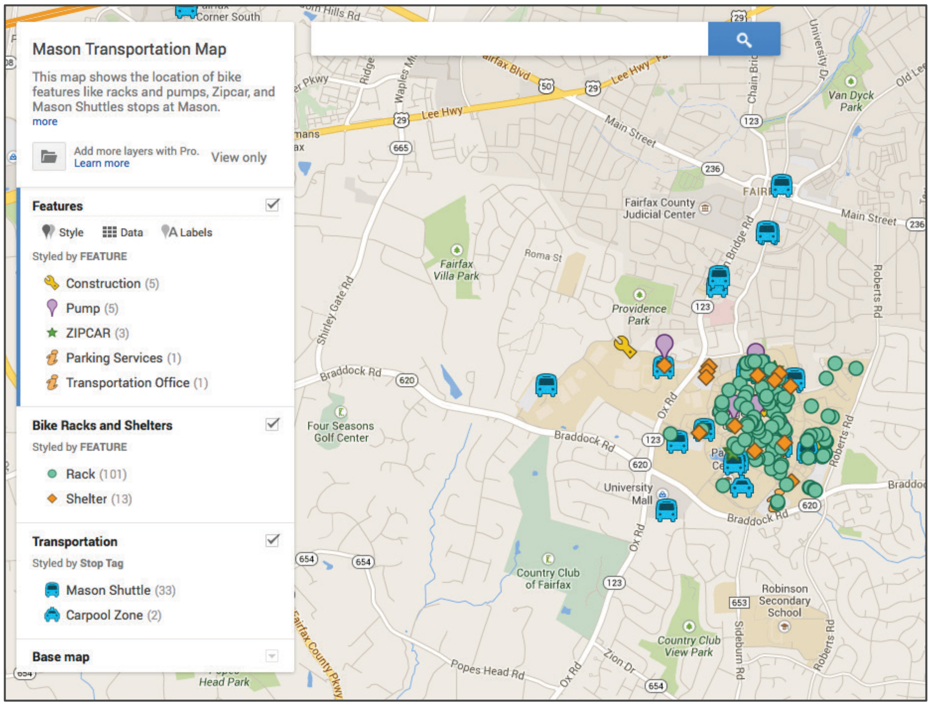


Figure 49. Jessica Fayne's Mason Transportation Mapping Portal

## Moderator Dashboard

Our moderator dashboard is being designed and developed to provide a means of connecting our data quality assessment work (described in Chapter 2 of this report) with the map-based visualization capabilities of GIS and the statistical graphics capabilities present in JQuery, a versatile, small, and fast JavaScript library for client-side scripting of computer graphics. Our current design (Figure 50) divides the display into two sections, with 60% of the horizontal screen dimension allocated to the map display and the other areas allocated to selection tools (sliders for filtering by report or obstacle parameters) and statistical graphics. The moderator dashboard's visualization tools are designed using JavaScript, AJAX, HTML, and CSS, on top of the same PostgreSQL database (v.9.2) used for our data collection tools.

We developed this tool to identify and visualize aspects of data quality that have unique temporal or spatial properties.

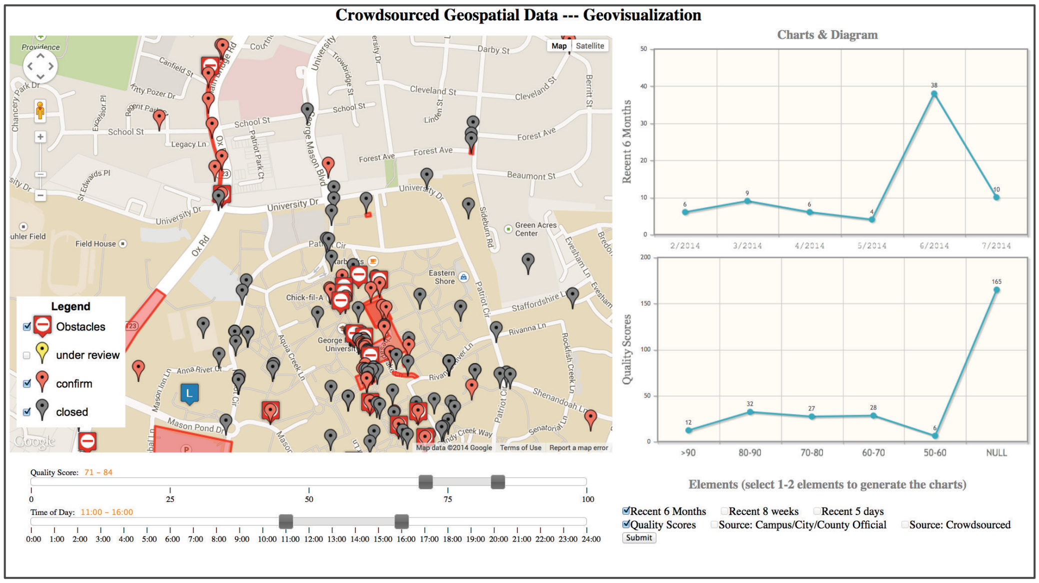


Figure 50. Visualization tool (under development), http://geo.gmu.edu/viz.html

Similar data visualization tools include Tableau Public, a free web-based interactive charting and graphing application. Novel exemplars from Tableau Public include graphics such as Figure 51, which shows user-IDs for contributors to our system, and displays the quality of their report contributions through time. In the upcoming weeks we will be implementing a variety of map-based and chart-based data visualization tools to explore the spatial and temporal dimensions of data quality.

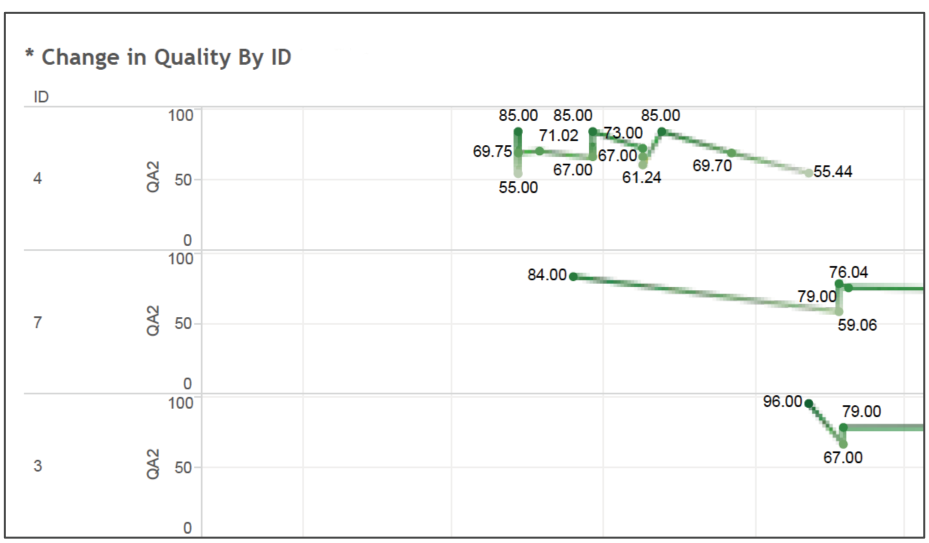


Figure 51. Tableau Public: Change in QA Quality by ID

## Conclusions and Summary

The Moderator Dashboard is an important extension of our GMU Geo-crowdsourcing Testbed. Visualization represents the emergence of an interactive, scientific approach to the traditional discipline of cartography, and has become an important part of a web-based system for analysis. Our visualization tools form the critical connection between our quality assessment activities and our mapping activities. The ability to create map and chart-based displays of report and obstacle data will help discover unknowns, as envisioned by the MacEachren Cube, and will lead us toward improvements in our work. Where possible, we will find and emulate the best examples of data visualization.

# 6 Conclusions and Future Directions

In earlier phases of this multi-phase research effort, we conducted a significant review and characterization of the state-of-the-art in crowdsourcing geospatial data (Rice et al. 2012a). This work has led us toward good ideas and best practices that have informed our design and implementation of a system for crowdsourced data collection, described in Rice et al. 2013. This report describes our effort to build a system for quality assessment, based on the best practices and associated science, a program for recruiting and training participants, and extensions of our testbed in the areas of accessible routing and visualization.

Methods for geospatial data quality assessment have developed over the past seven decades, and have evolved along with GIS. The current methods, built on the concepts of National Standard for Spatial Data Accuracy (NSSDA) and other best practices, include considerations for positional accuracy, attribute accuracy, completeness, logical consistency, semantic accuracy, temporal accuracy, lineage, and usage. Girres and Touya (2010), and Haklay (2010) provide useful applications of traditional data quality concepts to geocrowdsourced data, primarily OpenStreetMap. Goodchild and Li (2012) outline three general methods for quality assurance in crowdsourced geospatial data, one of which (the social approach) matches our approach for quality assurance. The use of trained student moderators to provide a comprehensive quality assessment, based on best practices, allows us to assess the quality of the positioning and attributes of reports. These moderator-led data quality actions, outlined in Chapter 2 of this report, result in general quality measures that we use to analyze the crowdsourced geospatial data and explore geocrowdsourcing dynamics in our system.

Project researcher Fabiana Paez conducted an extensive review of training approaches for crowdsourced geospatial data, concluding that an embedded, modular approach would benefit our project, similar to the approaches used by Google Map Maker and Waze. Through her work, we have trained more than 200 potential contributors, some of whom have contributed to our system. Based on the insights and conclusions in her Master's Thesis, we will revise our training program to integrate it with our data contribution tools, which matches some of the practices advocated by researchers interested in the effectiveness of computer training programs.

Extensions of our GMU Geocrowdsourcing Testbed include accessibility routing (discussed in Chapter 4) and visualization (discussed in Chapter 5). The accessibility routing work, which is of high interest to local collaborators, has shown to be interesting and challenging, due to the highly variable preferences and individual decisions associated with route choice. A few of these significant preferences, such as slope and curvature, will be implemented within our GMU Geocrowdsourcing Testbed routing extension. The visualization extension to our GMU Geocrowdsourcing Testbed has a purpose of connecting our data quality metrics to our mapping system. Innovative statistical graphics are being developed to help illuminate and explore spatial and temporal relationships in our data.

Final items for future work include the following topics that have emerged during our work this year. We plan on conducting an analysis of the influence that map base layer (and its level of detail) have on the quality and completeness of information contributed to our testbed. Additionally, we plan on conducting a series of checks for moderator consistency in defining the "ground truth" for position and attributes of reports, which is a foundational element of our quality assessment. We will also look closely at the influence of the computer input device (mobile, tablet, desktop) on the precision and accuracy of report location, and plan on extending this idea to include other positional indicators, such as embedded image geotags and text-based location description. These future research areas will help us understand the dynamics of geocrowdsourcing and will help us improve the GMU Geocrowdsourcing Testbed.

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